nHCal (backward hadronic calorimeter)

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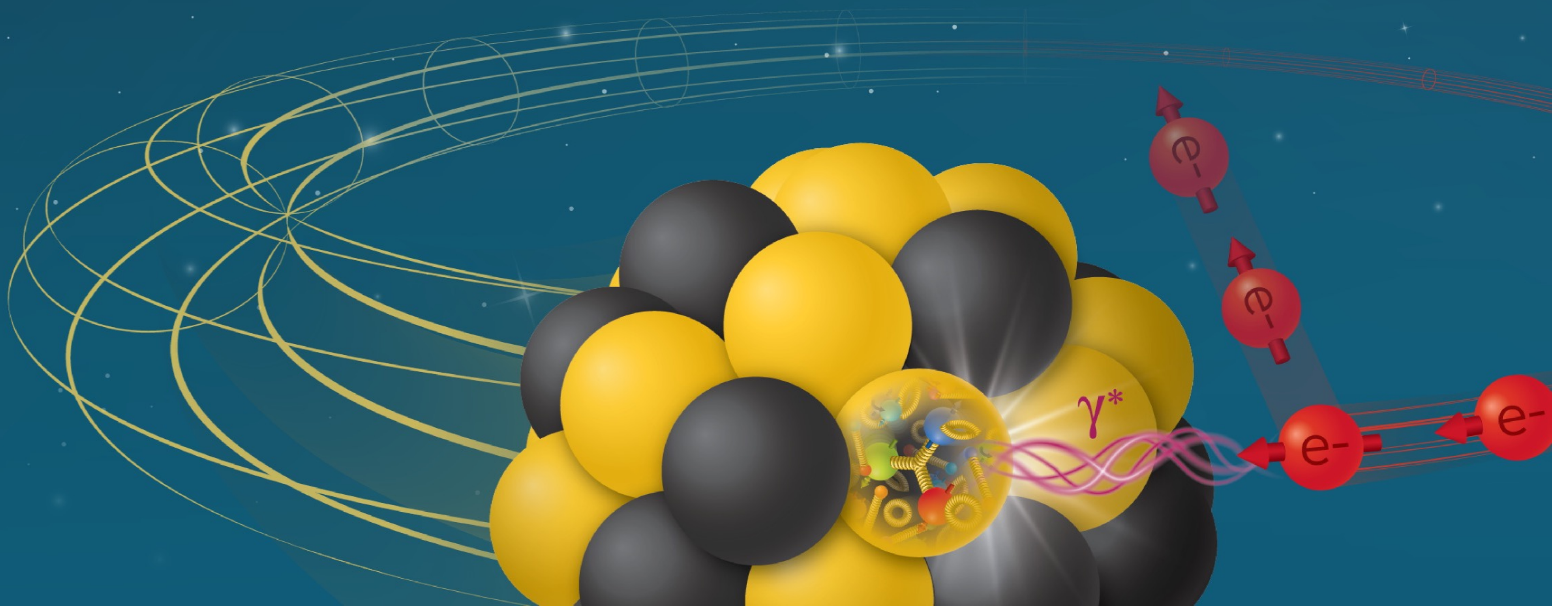
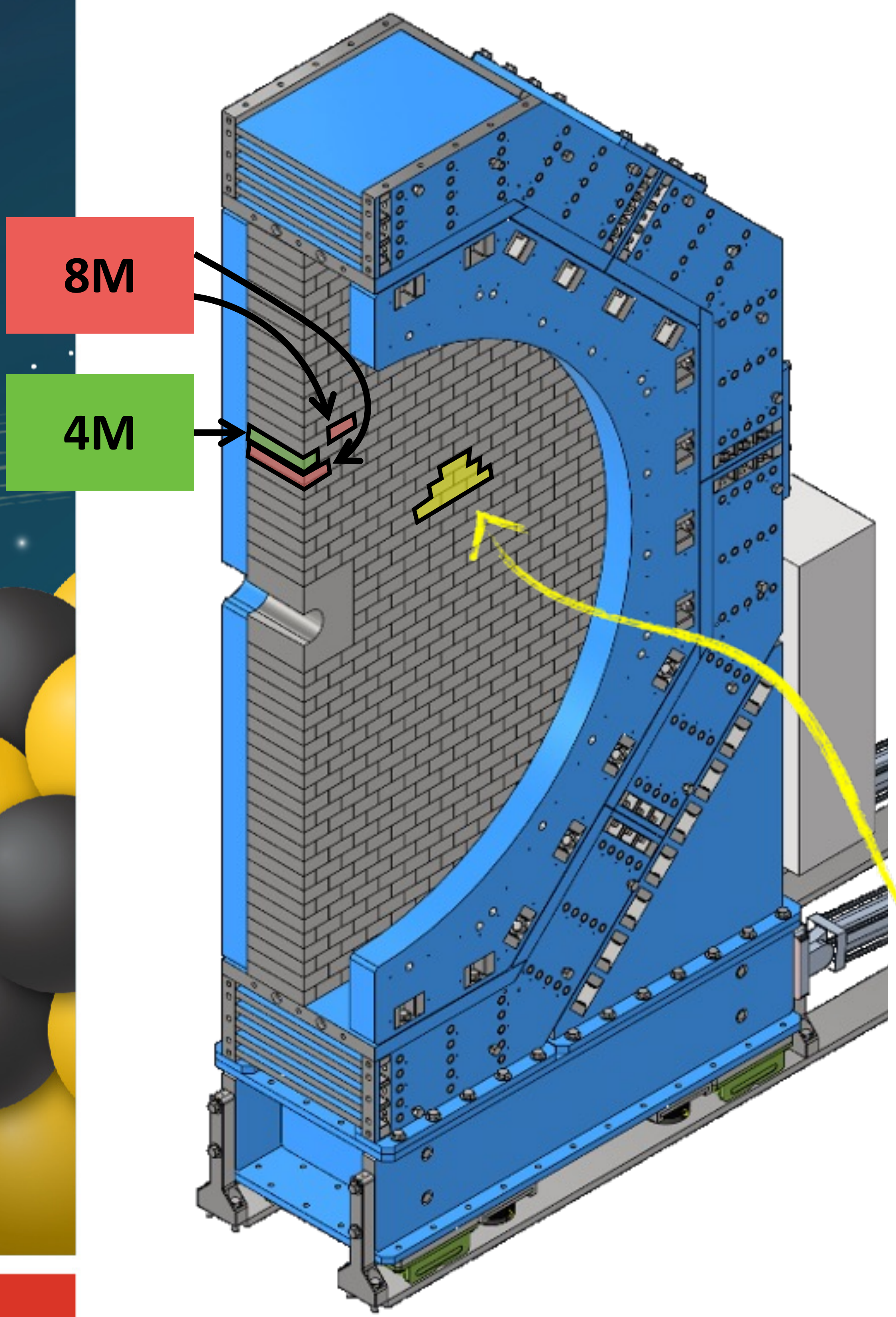
Incremental Preliminary Design and Safety Review
of the ePIC Hadron and Forward Electromagnetic Calorimetry
October 30th – 31st, 2025



Electron-Ion Collider

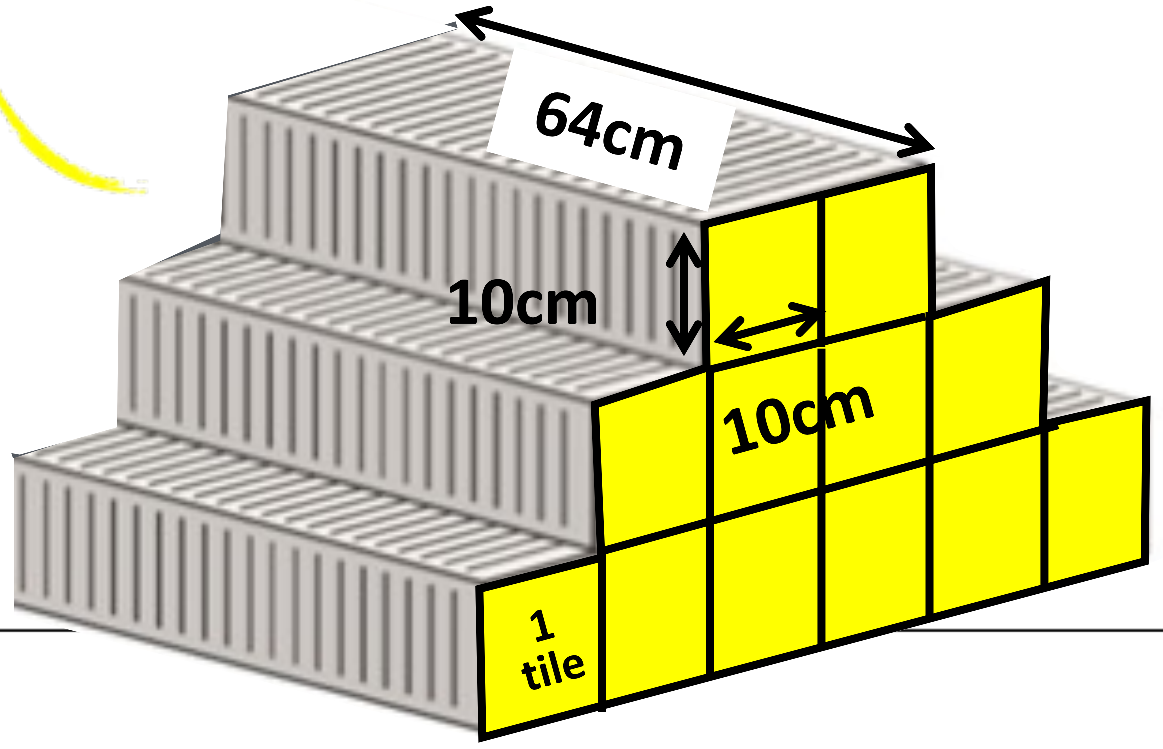
Backward (electron-going) hadronic calorimeter - **nHCal**

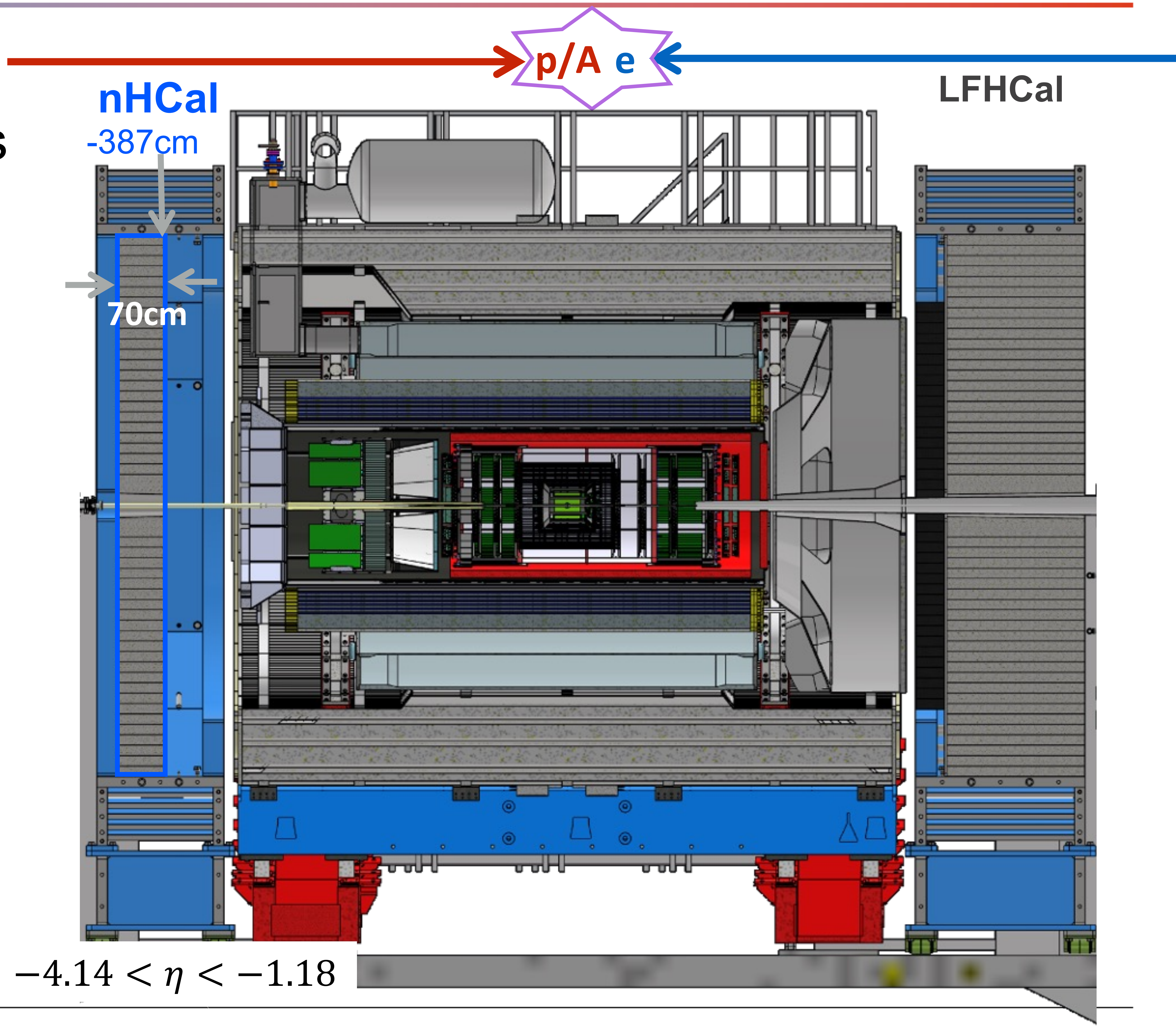
- Tail catcher calorimeter with sampling approach, alternating Fe / Sci Tiles layers
  - Synergies with LFHCal (choice of technology)



- Interaction lengths: 2.4 (LFHCal: 6)
- up to ~70cm available (including electronics)

20 layers of each
2 cm steel +
1.2 cm scintillator



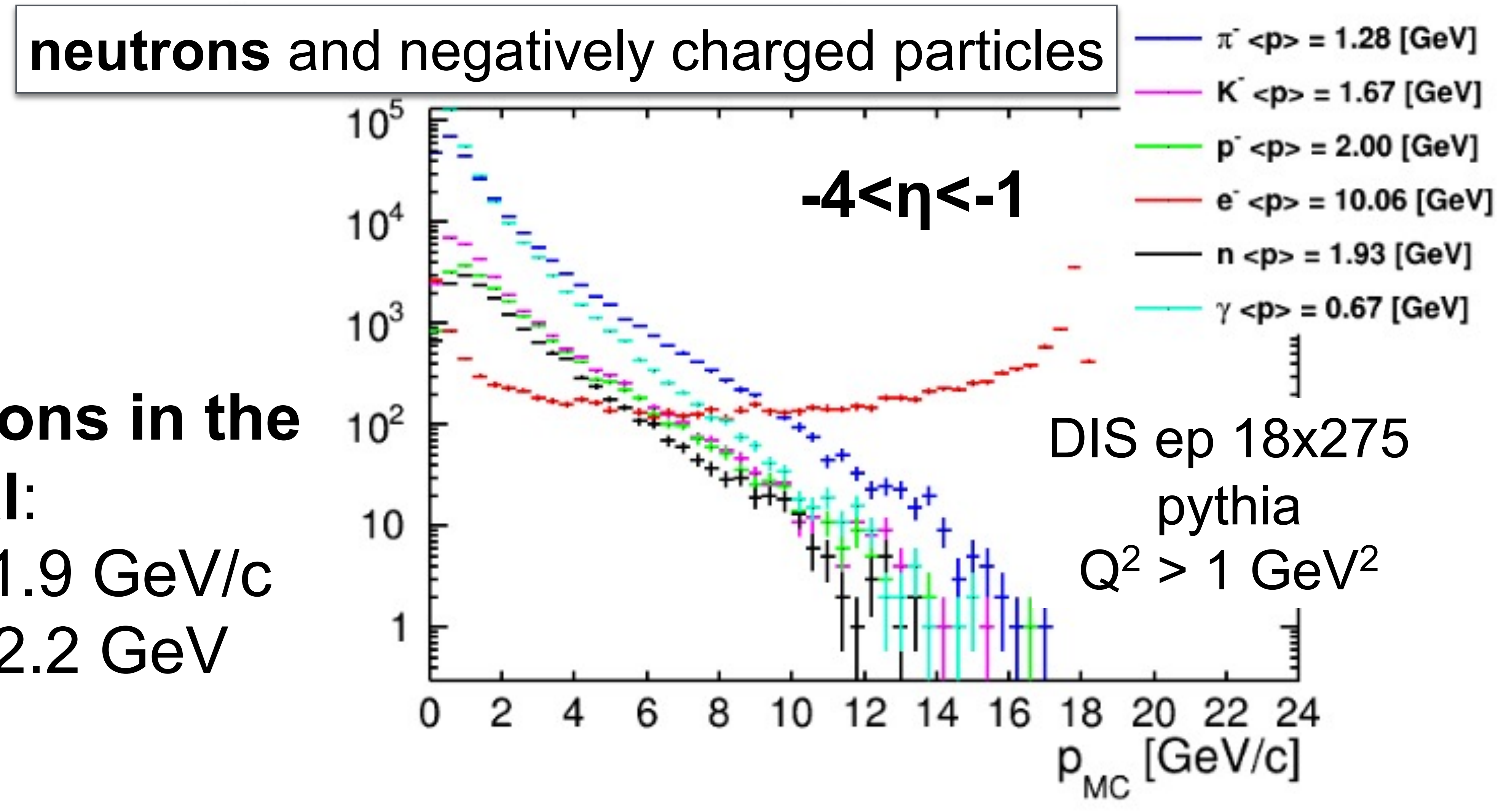


$-4.14 < \eta < -1.18$

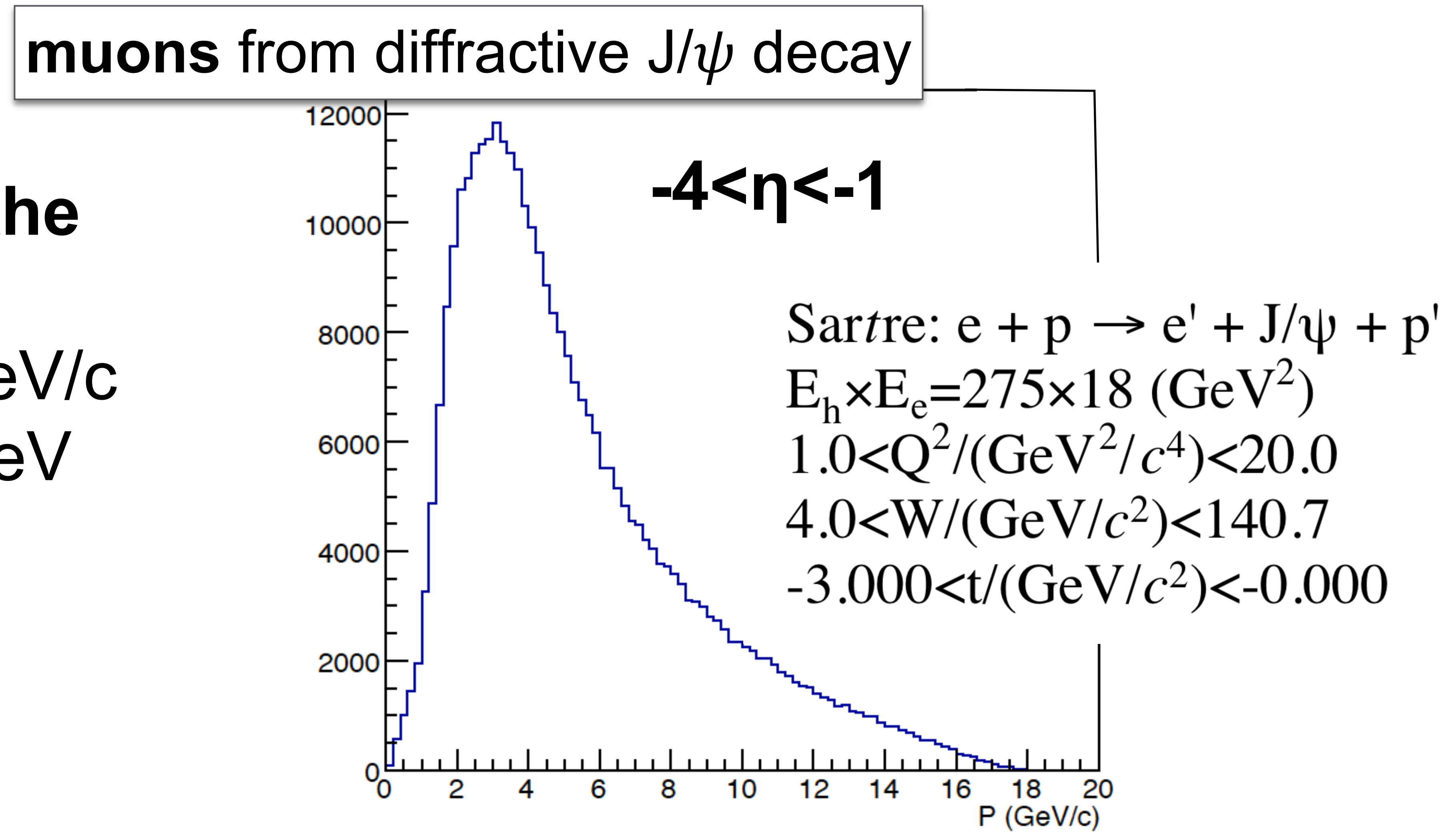
Main purpose of nHCal

- Tail catcher calorimeter in the backward (electron-going) direction
- Important for low-x and -Q2, high-y (high gluon densities) - **core aspects of EIC physics mission**
  - Diffraction, neutral and charged jets
  - Neutron detection and muon ID
- Lessons learned from HERA / H1 backward SPACAL [NIMA 386 (1997), 397-408](#) [PLB 665 (2008), 139-146](#)
- Tail-catcher: design optimized for particles in the few to 10s of GeV range

neutrons in the nHCal:
<p>=1.9 GeV/c
<E>=2.2 GeV



muons in the nHCal:
<p>=5.3 GeV/c
<E>=5.3 GeV



nHCal design optimization via simulations - overview

Are the technical performance requirements appropriately defined and complete for this stage of the project?

Design optimization

Physics impact ➡ Design parameter ⬇	σ_E/E	Eff	μ/π sep.	λ_{int}
Gross length	x	x		
Tile configuration	x	x		
Z-layer readout	x		x	
Sampling fraction, absorber/scintillator ratio				x
Absorber material	x			x

- Parameters: transverse tile size, number of layers, scintillator & absorber thickness
- nHCAL: 1st layer (nearest IP) is scintillator
  - Improve neutral vs. charged hadron separation
- Dedicated simulations
  - Single particle, DIS, Diffractive events
  - Then full simulations with background
  - Absorber material fixed by external constraints
    - Non-magnetic material (magnet system)
    - Risk + cost prohibit use of e.g. W, depleted U

5x5 or 10x10	scintillator thickness	0.4				0.6	0.8	1.2
[cm]	absorber thickness	4	3	2	1.5 2	2	4	2
10 layers		45						
12 layers		54						
13 layers			46					
15 layers		68						
20 layers				50		54	58	64
28 layers					57			

gross length

nHCal configuration (10x10 tiles)

LFHCal configuration (5x5 tiles)

D. Brandenburg (OSU) , C. Riedl (UIUC)

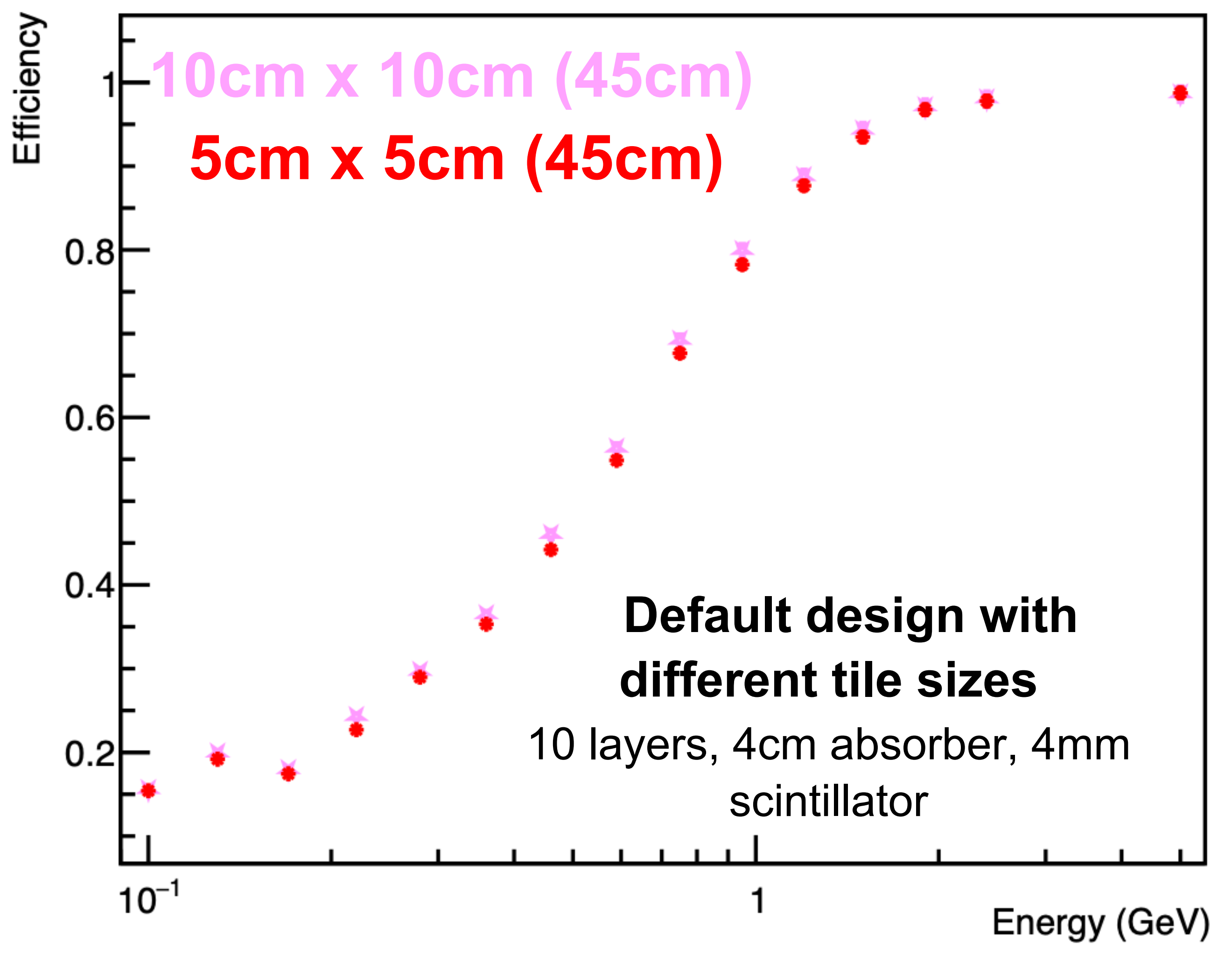
Design Optimization: Efficiency for neutrons

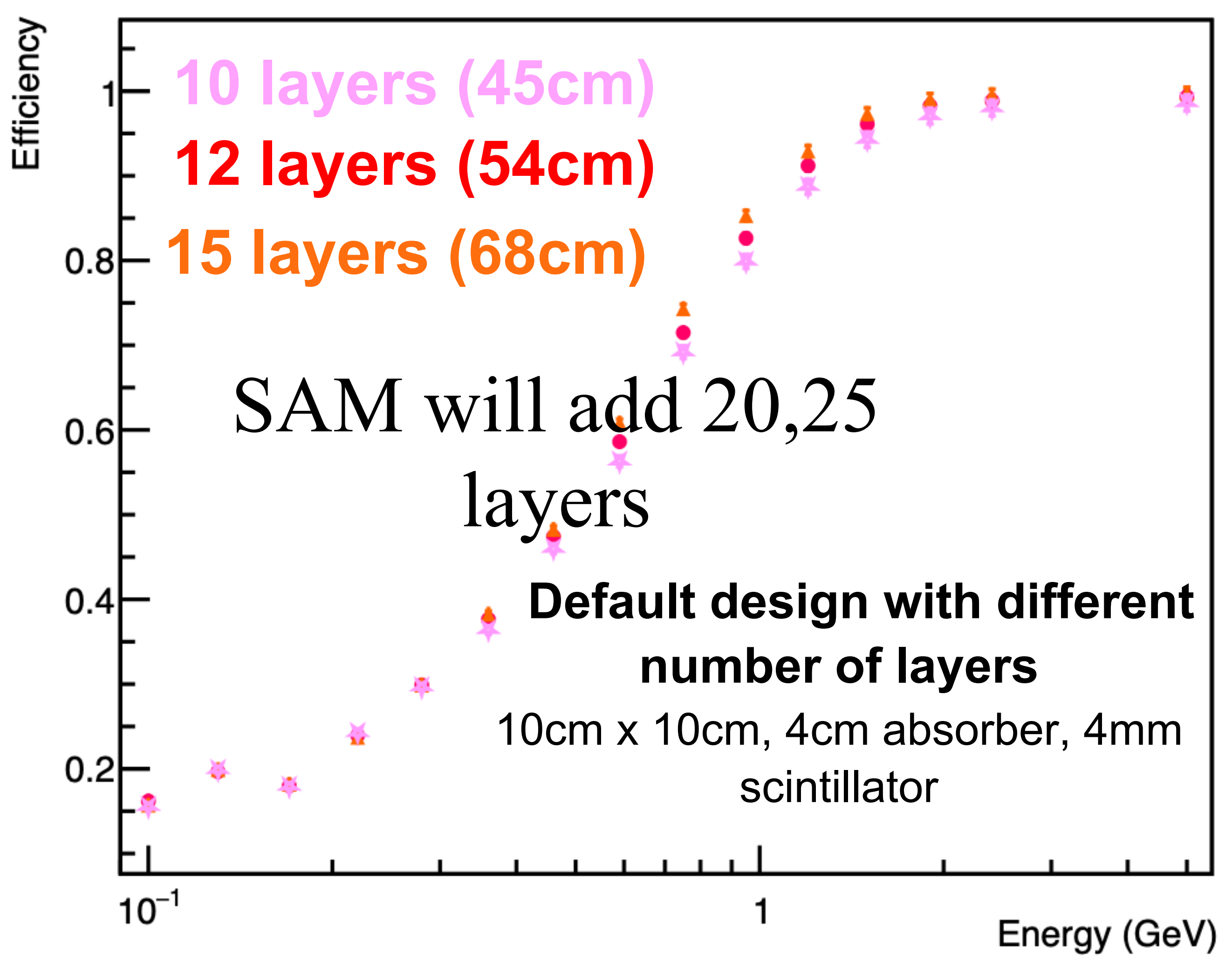
As a tail-catcher, low energy neutron detection is key design metric for nHCAL

- Tile size has negligable impact

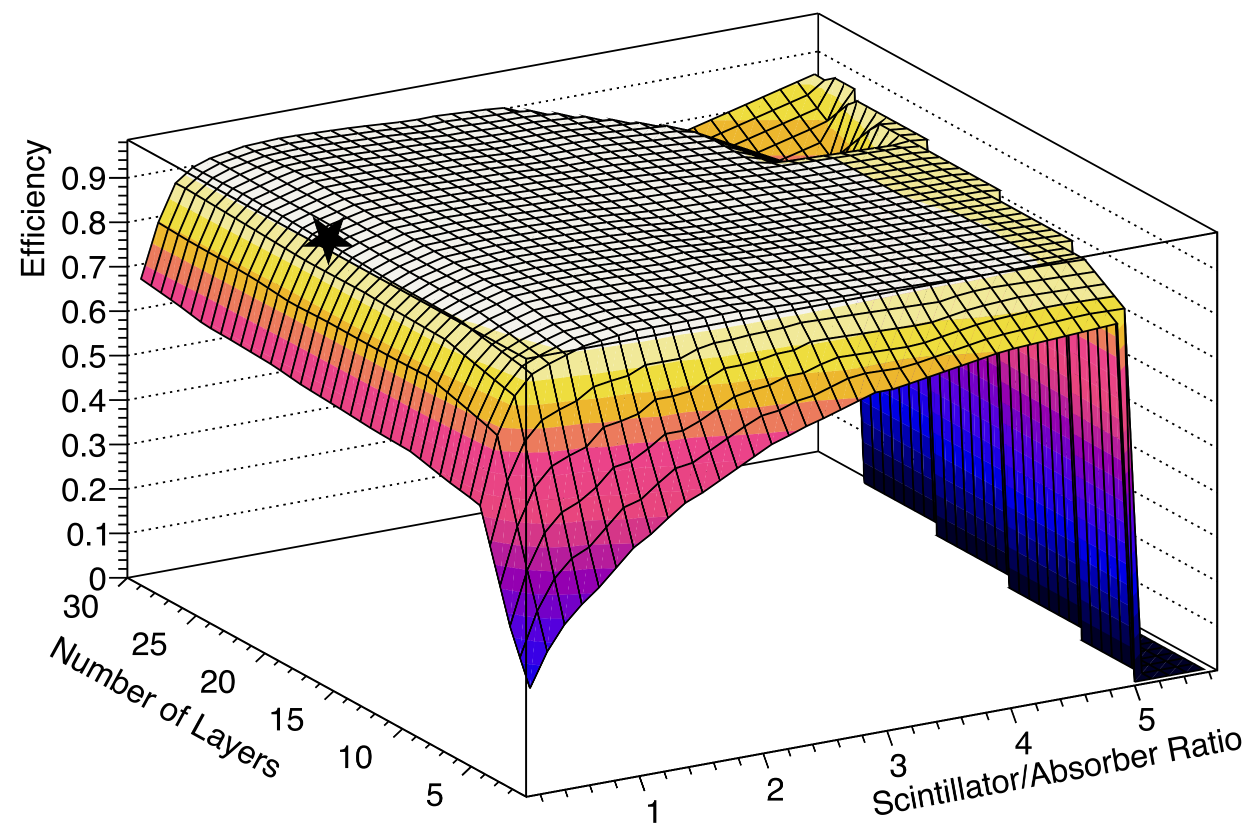
- Efficiency increases with
  - Number of layers (⇒ length of calorimeter): 10 → 15 layers increases efficiency by about 5% for 1 GeV neutrons
  - Scintillator / absorber ratio: scintillator 4mm → 8mm increases efficiency by nearly 20% for 0.5 GeV neutrons

Constraints on <u>gross length</u>, <u>tile configuration</u>, <u>absorber/scintillator ratio</u>

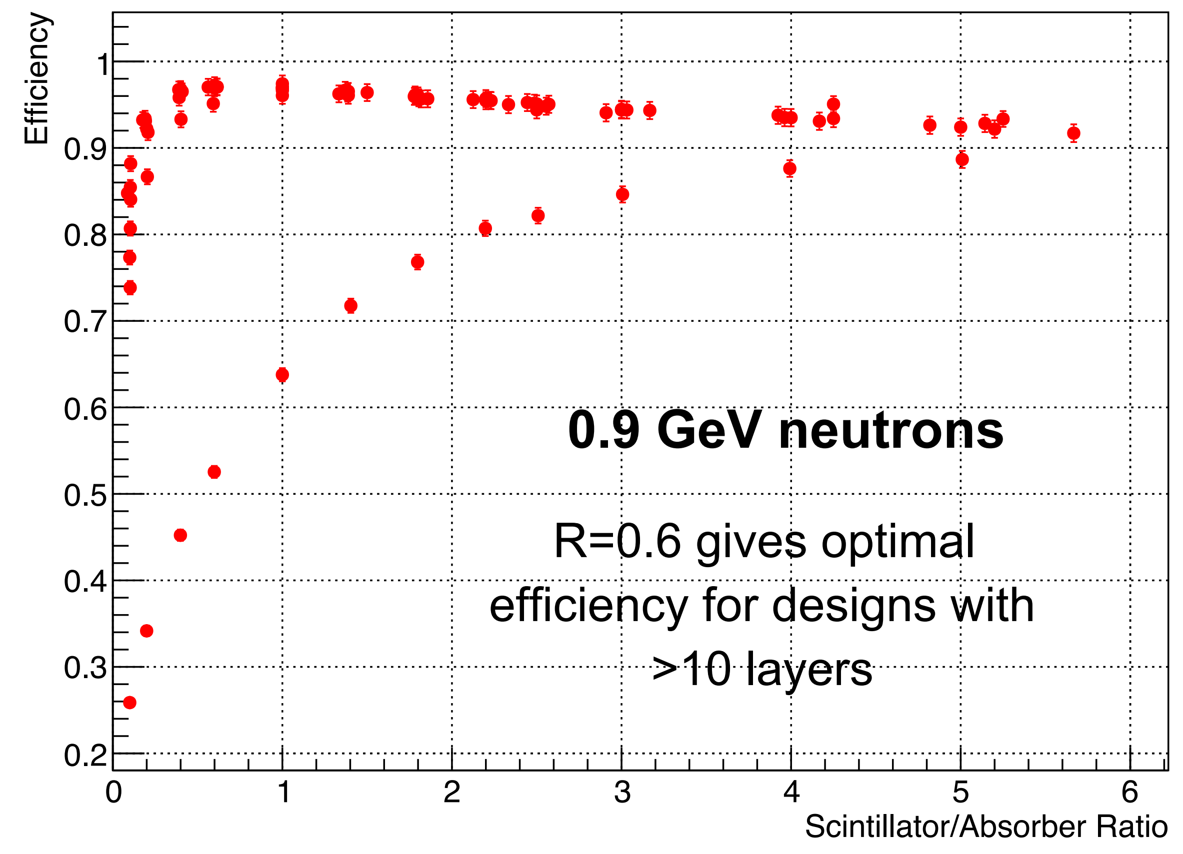




Neutron Detection Efficiency



Scintillator/Absorber Ratio vs Efficiency

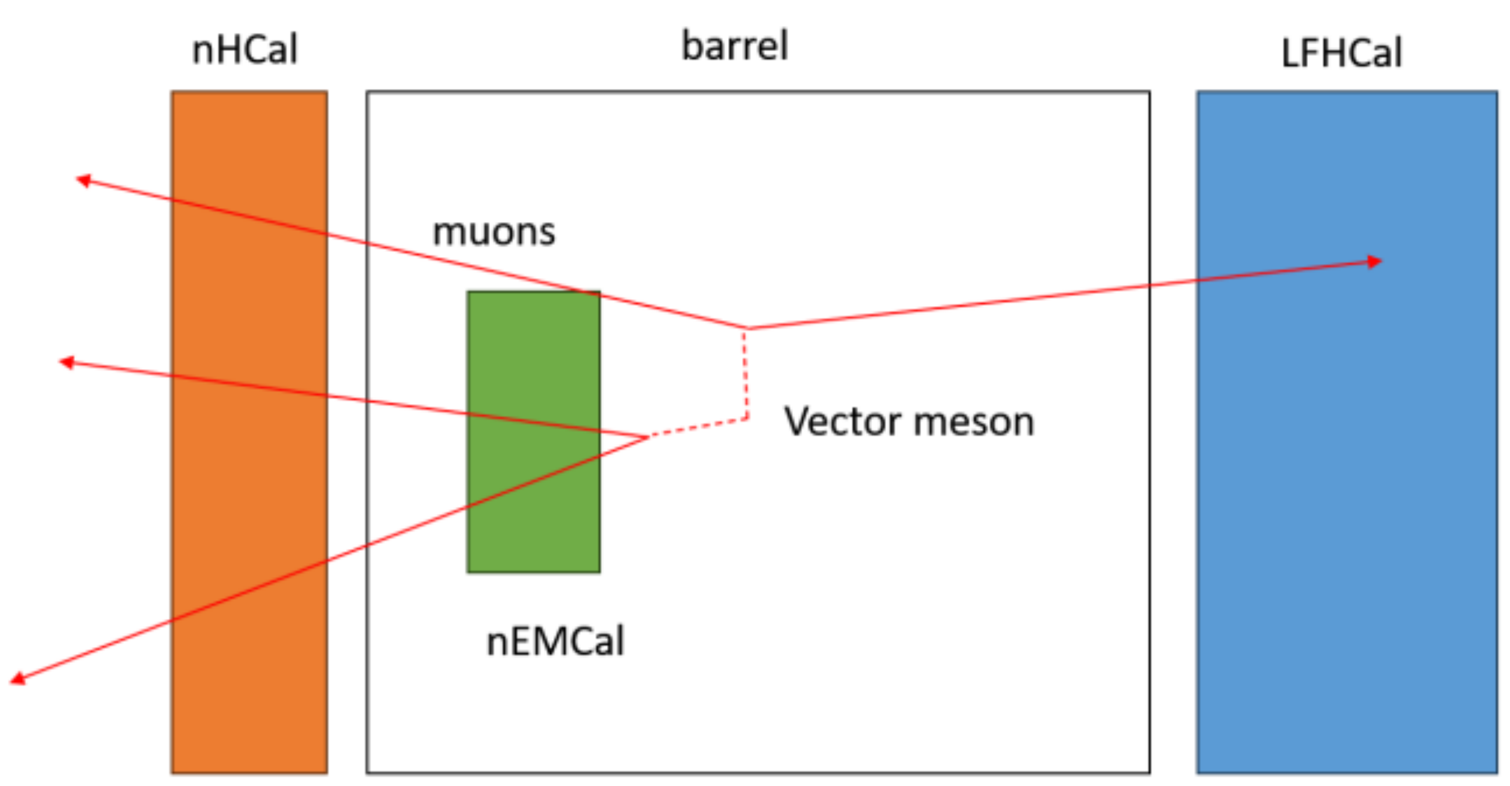


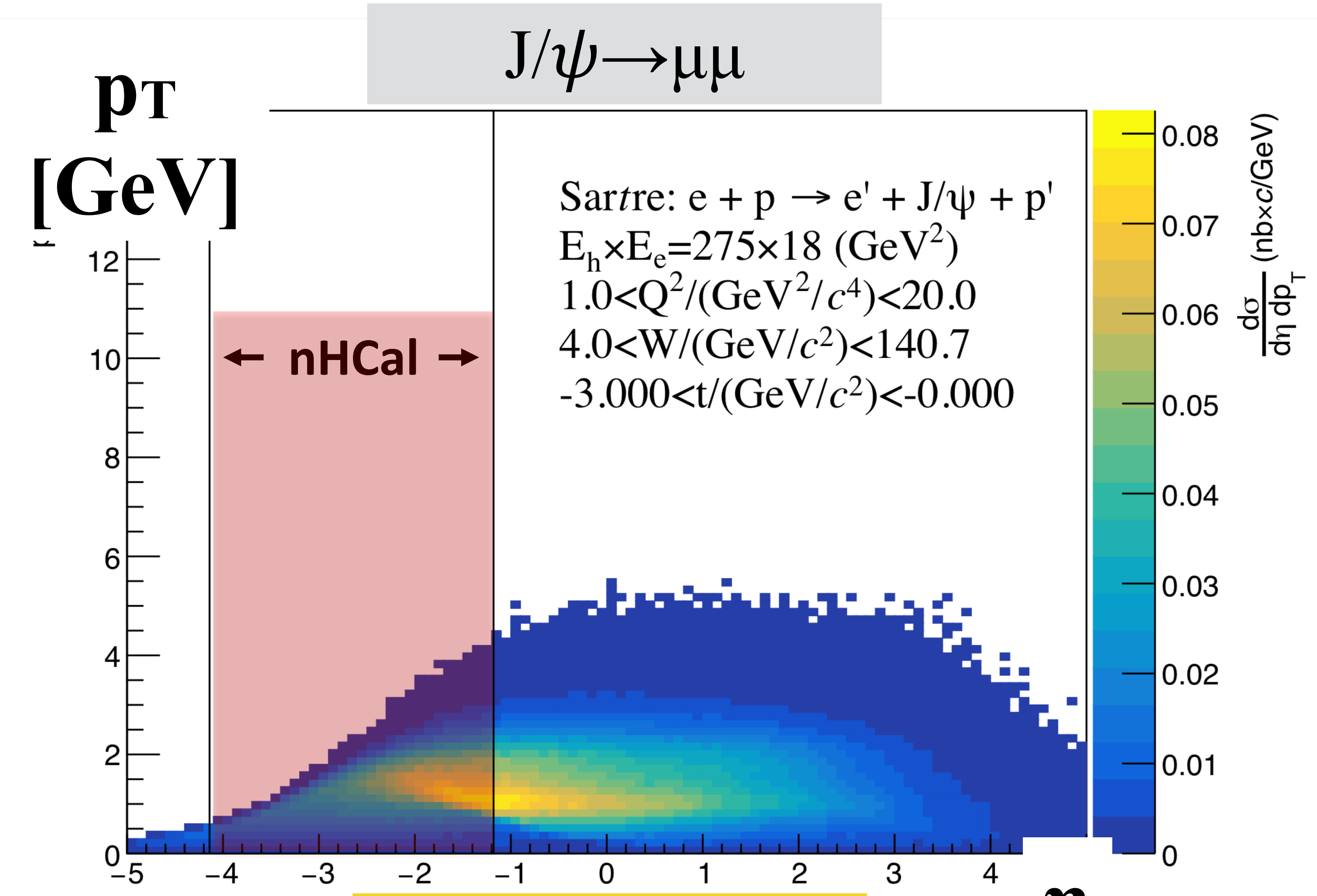
Sam Corey (OSU)

VM decays & muon Identification

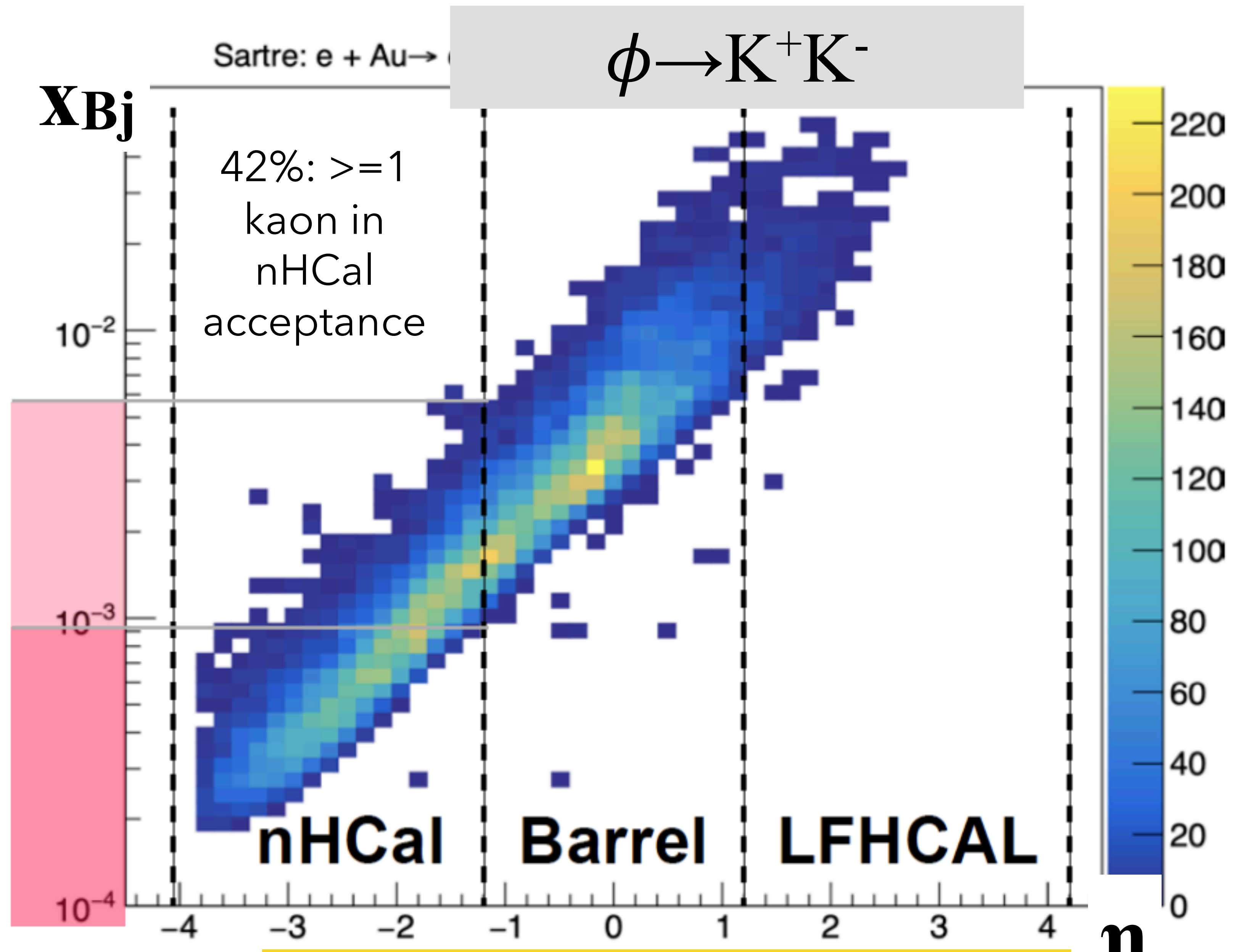
- Additional backward acceptance provides access to a more complete set of vector-meson decay topologies
  - nHCal crucial for low-x + non-ambiguous channels (vs. e^+e^- final states)
- Design Optimization for Muon ID
- Optimization metric = $\varepsilon_\mu(p,\eta) / \sqrt{\alpha_{h\to\mu}}$
  - With ε_μ = muon efficiency, $\alpha_{h\to\mu}$ = hadron mis-id rate

Constraints on <u>gross length</u>, <u>tile configuration</u>, <u>readout</u>

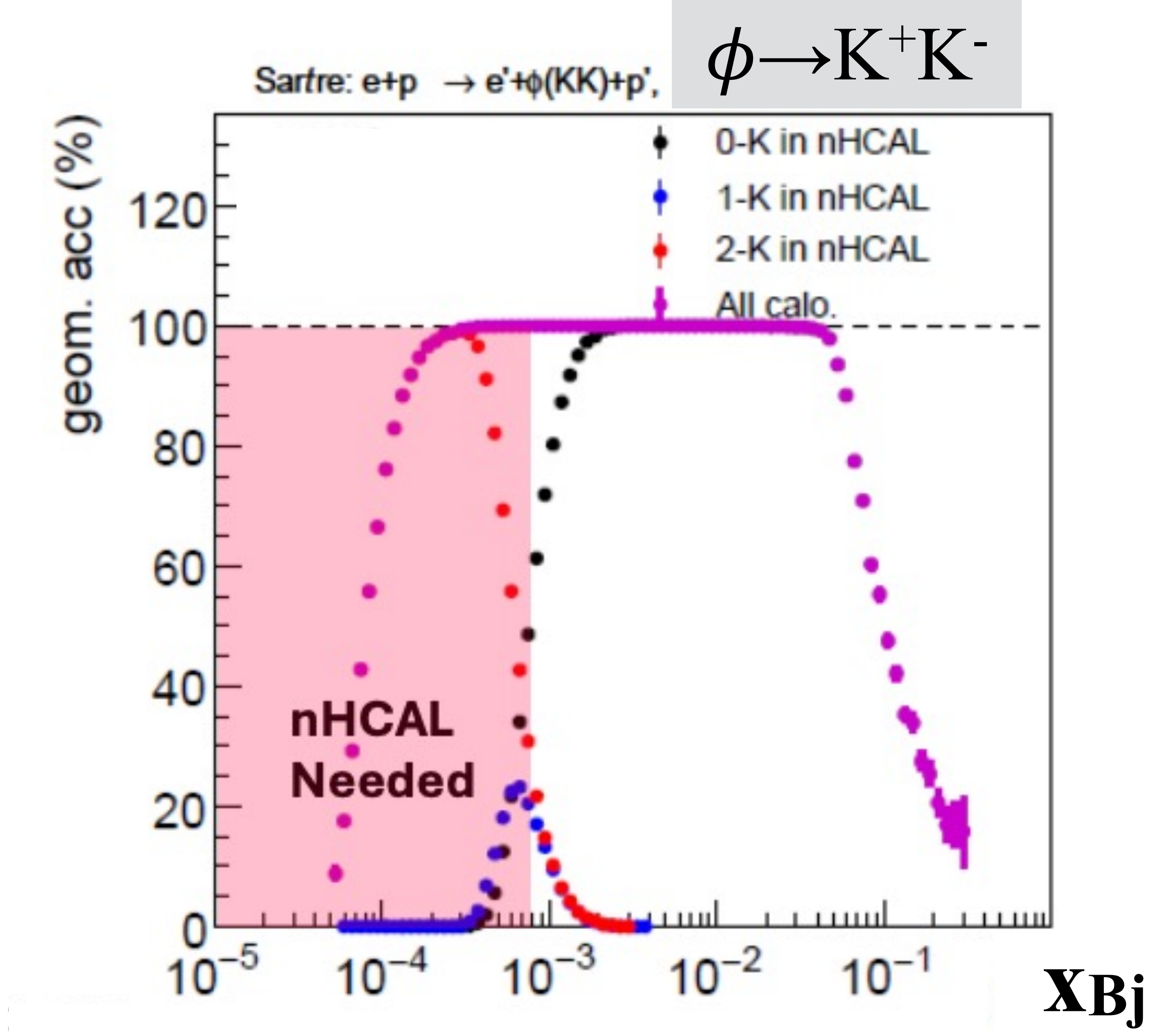




Vincent Andrieux (UIUC)



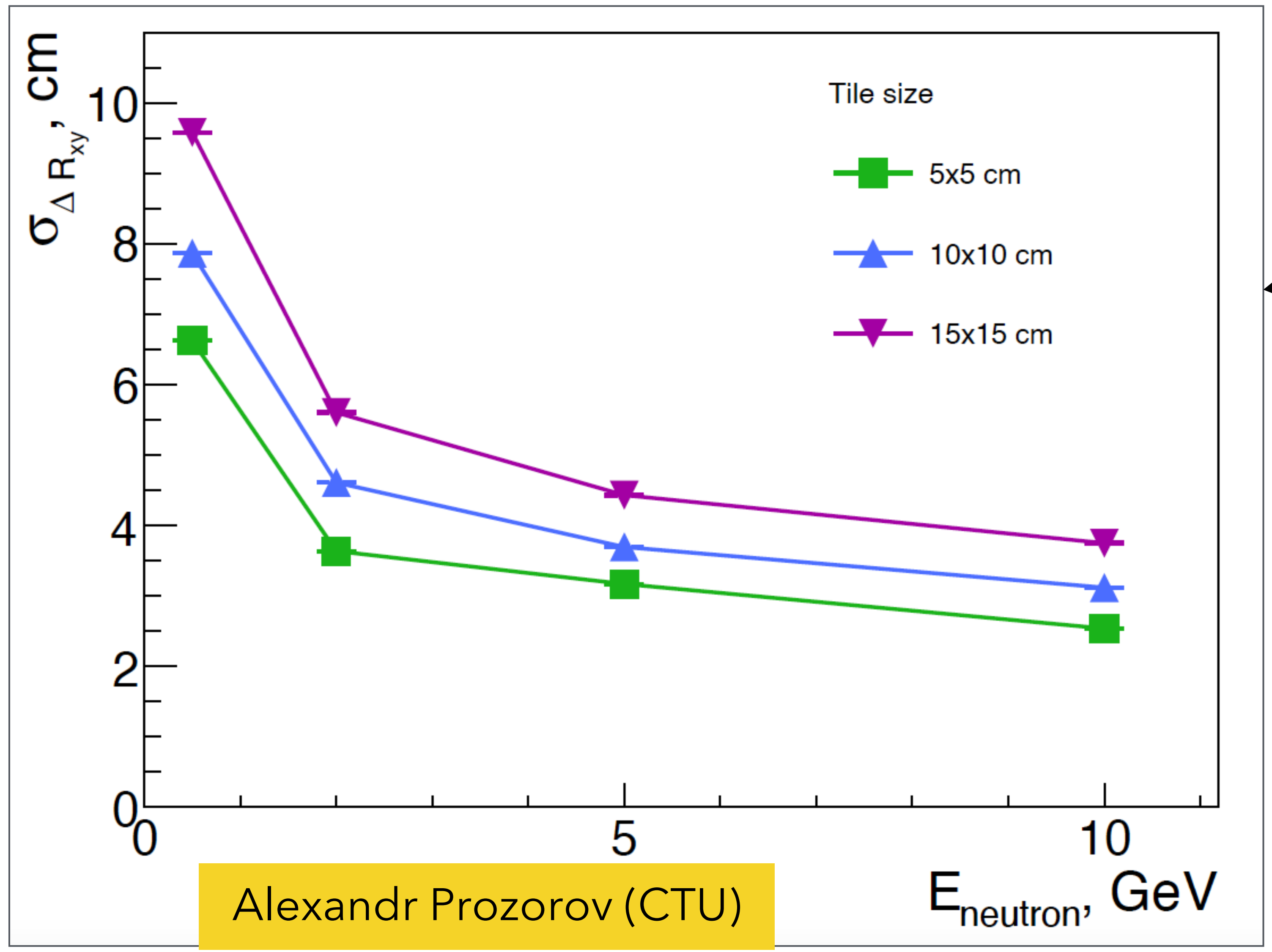
Dhruv Sharma, Roland Nothnagel (UIUC)

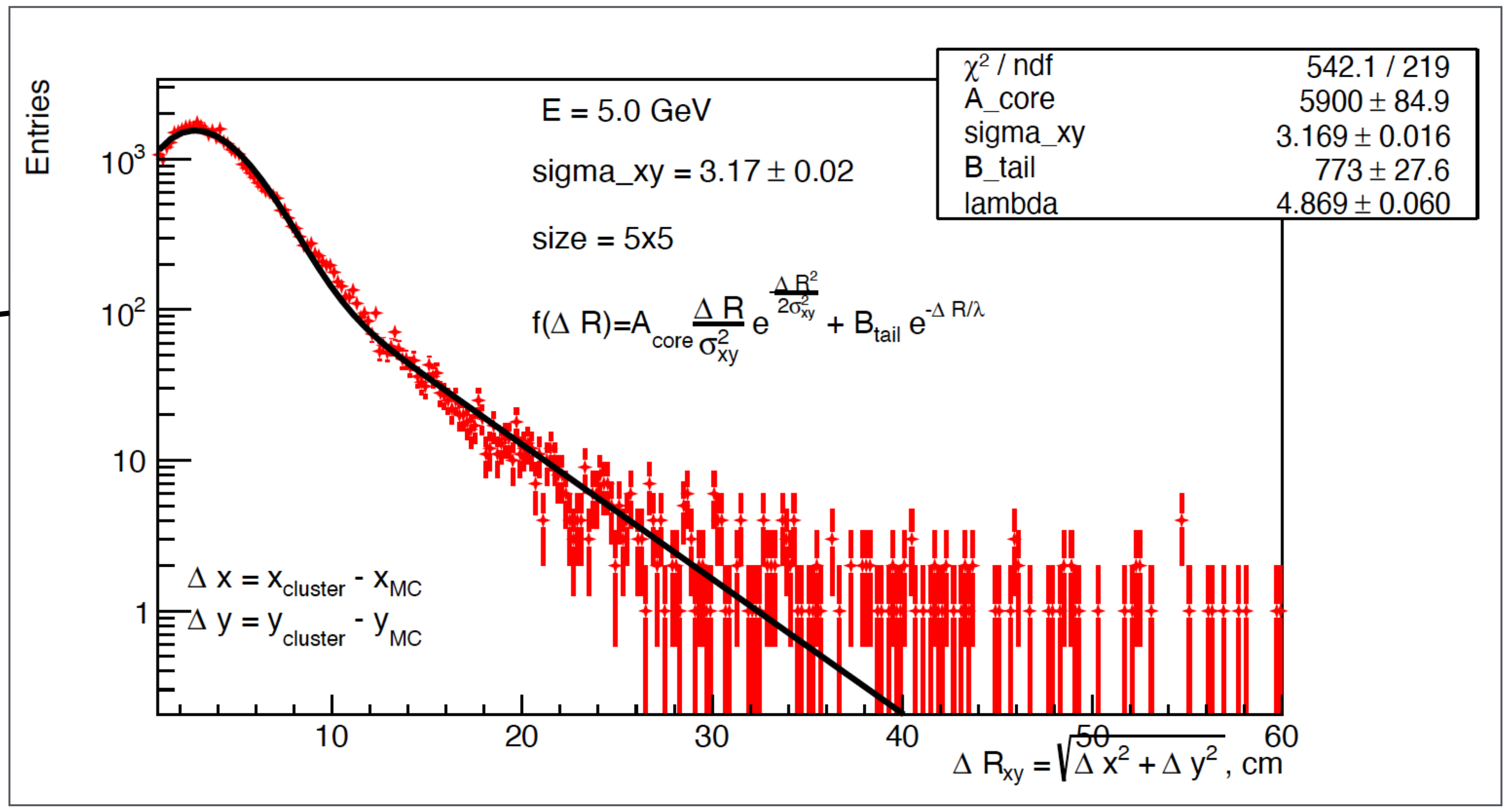


Position resolution for neutrons

Constraints on tile configuration, readout

- Transverse position resolution
  - Test position resolution varying tile size
- Neutron position resolution insensitive to tile size
  - As expected due to large transverse size of clusters

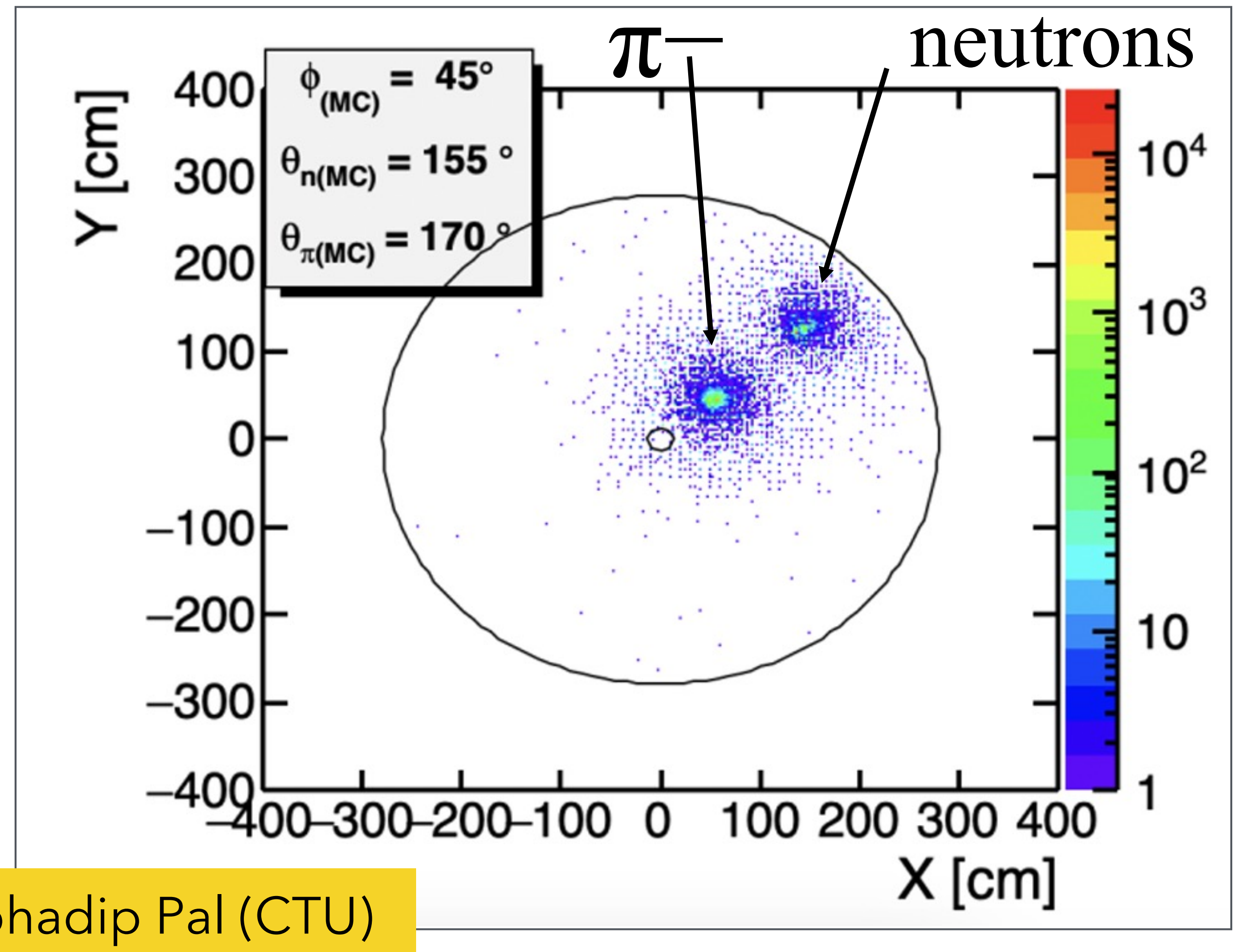


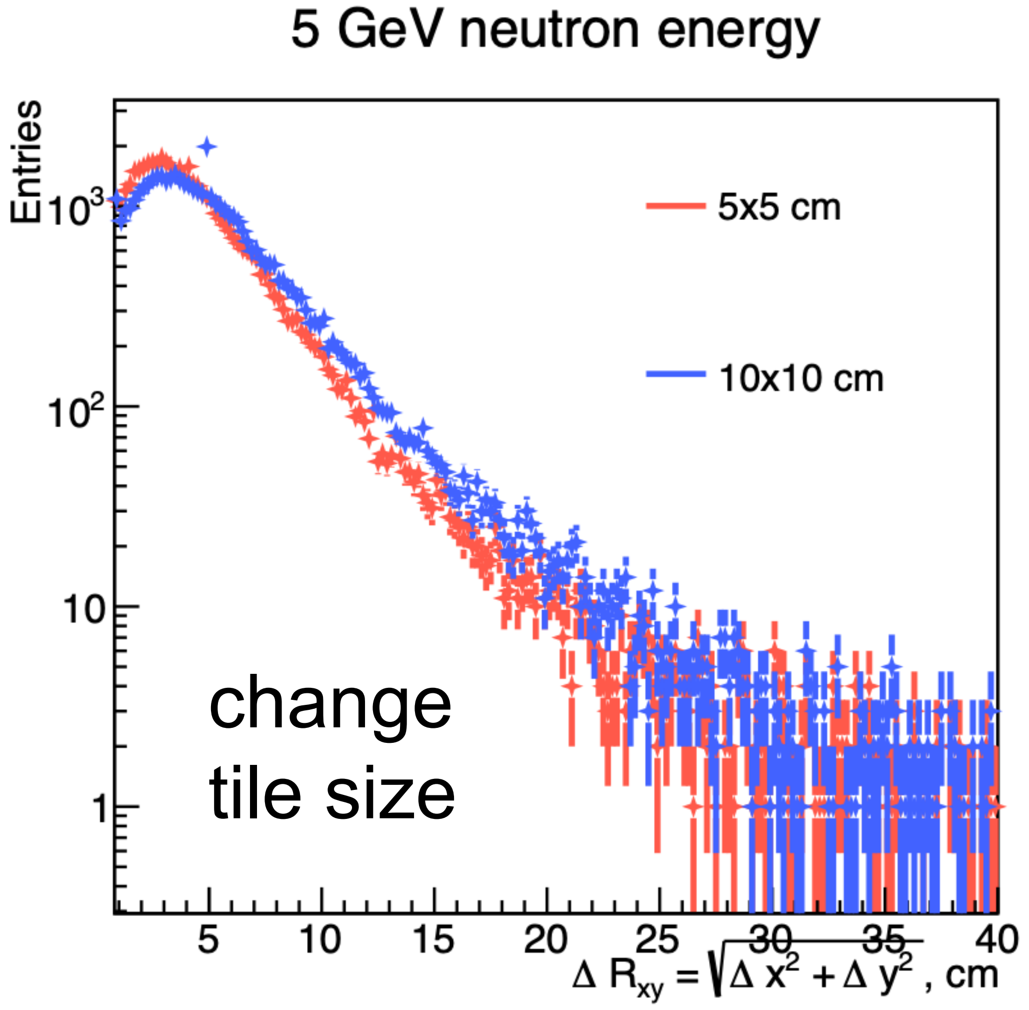


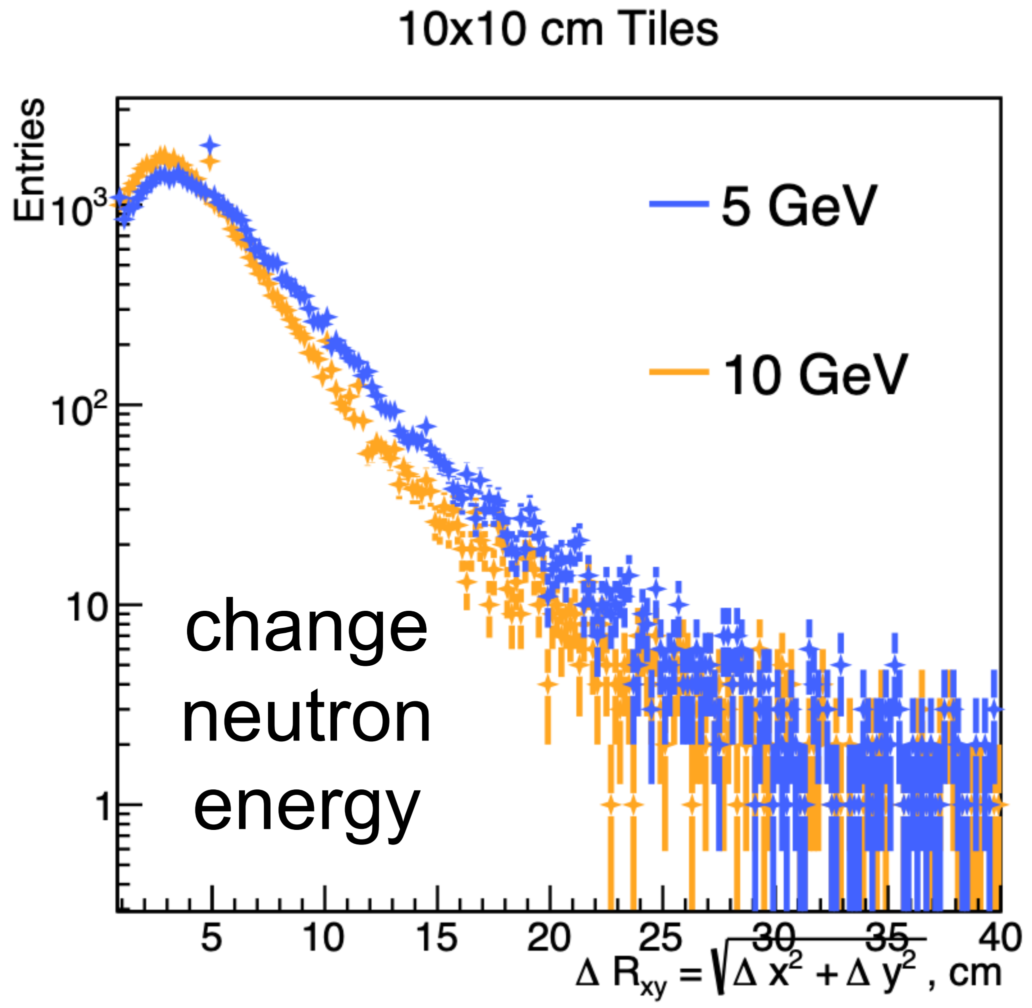
$$\Delta R_{xy} = \sqrt{\Delta x^2 + \Delta y^2}$$

$$\Delta x = x_{cluster} - x_{MC}$$
$$\Delta y = y_{cluster} - y_{MC}$$

- Neutron and pion clusters can be distinguished when separated by ~30cm





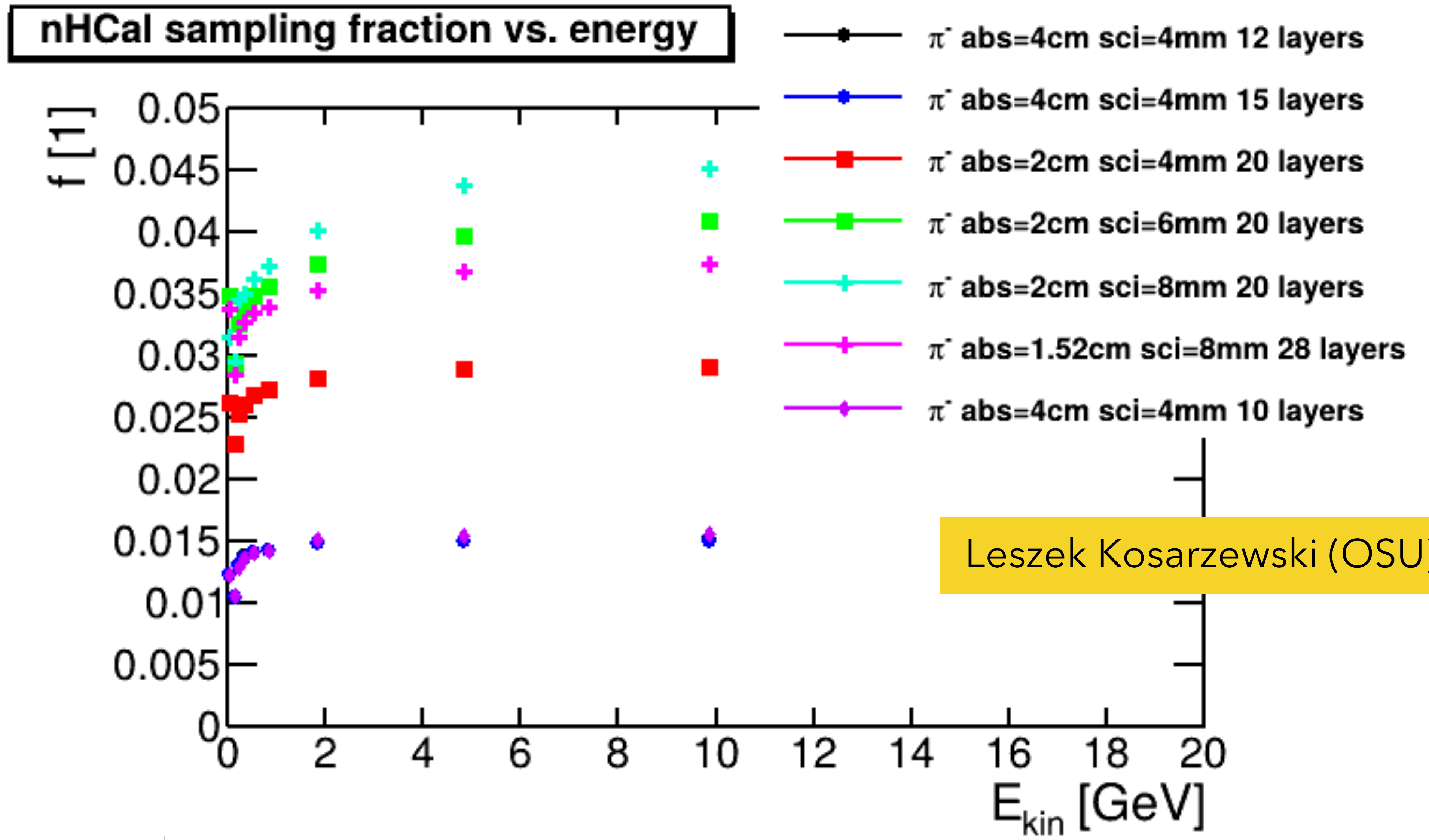


Sampling fractions and gross detector length

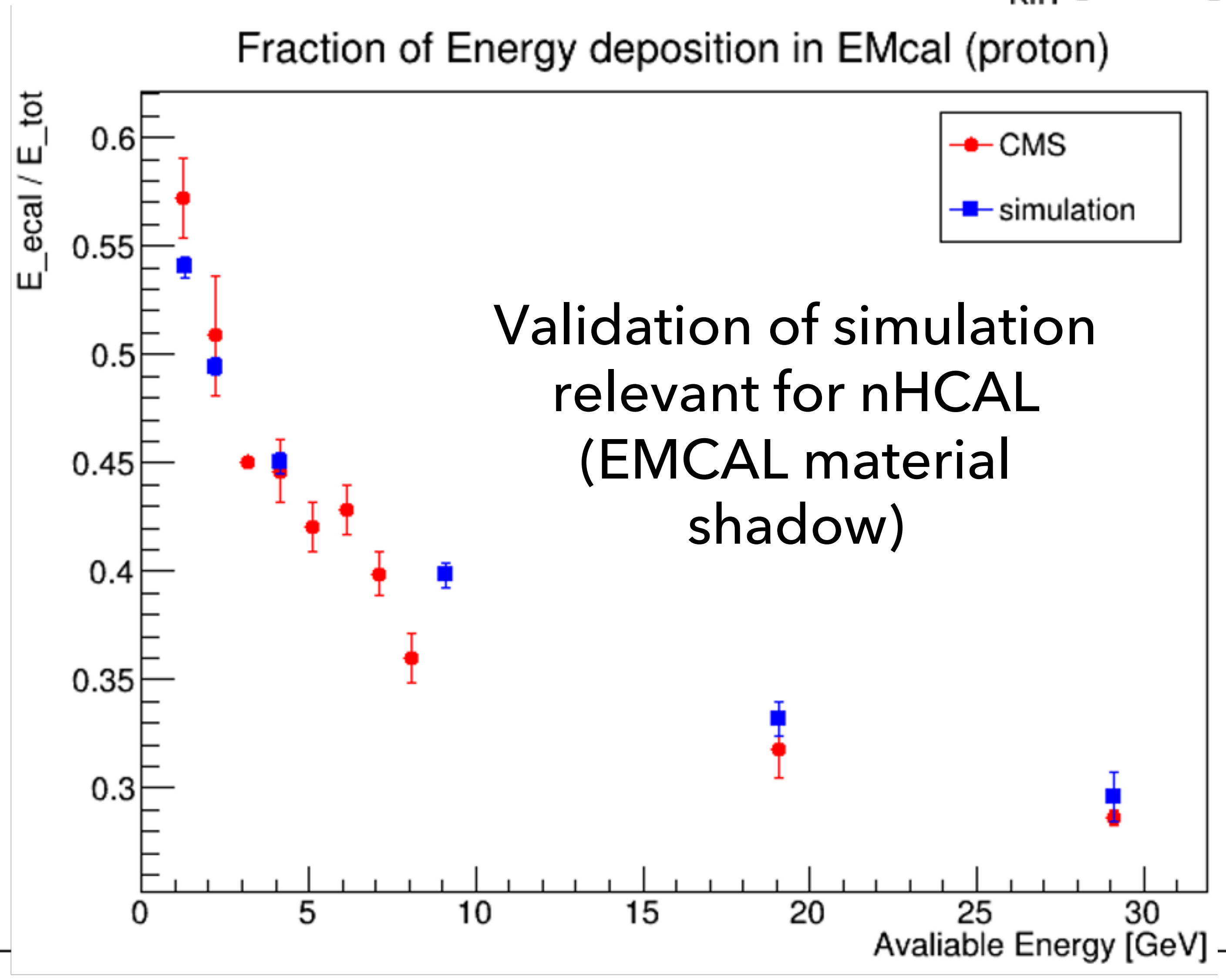
Sampling fraction = energy deposit in absorber / incident energy

- ~ 3-4% for optimal design (10x10, 20 layers, 2cm absorber, 1.2cm scintillator)
- Not dependent on particle species (n or π^-) - reflects how much of a particle shower can be sampled
- Not dependent on tile size (10x10, 5x5) but ratio abs/sci
- Design optimization driven by other parameters for tail-catcher (i.e. neutron eff, muon id, etc.)

- Also validated understanding and simulation uncertainty of the material budget upstream of nHCal (primarily backward EMCAL)



Leszek Kosarzewski (OSU)



Tianhao Jin (OSU)

CMS EMCal + HCal beamtest
https://cds.cern.ch/record/1046333

Constraints on gross length

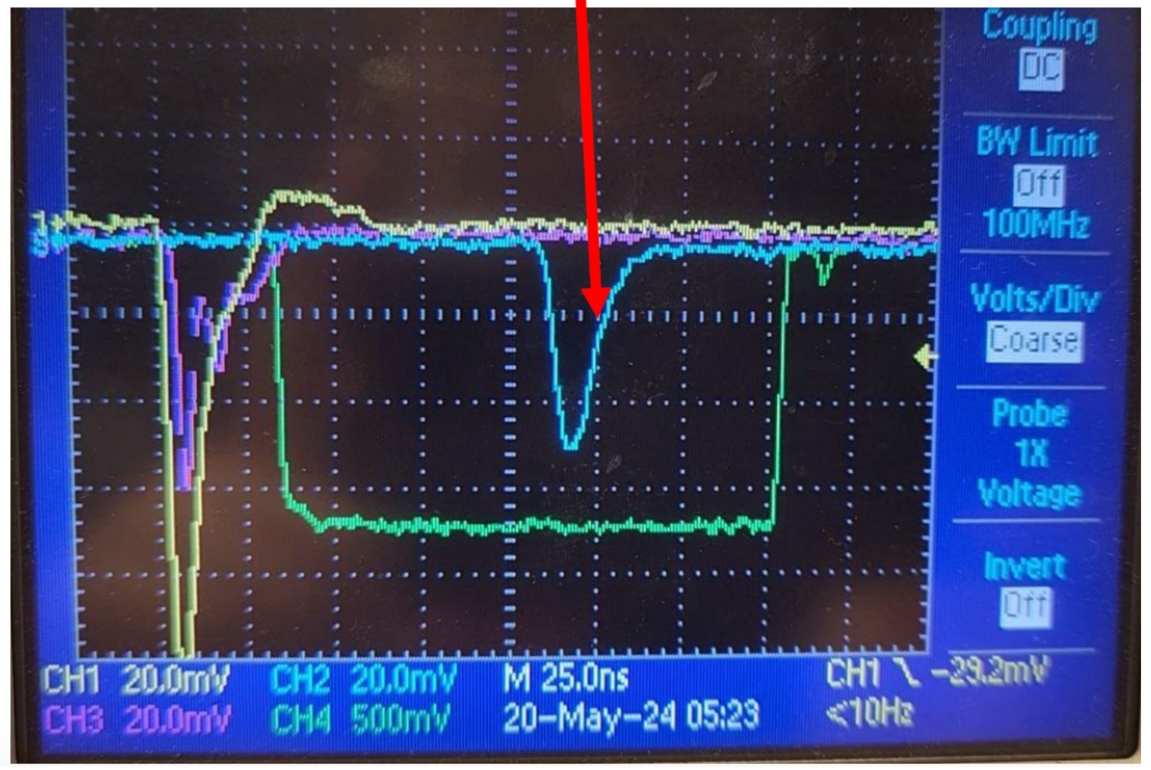
nHCal performance evaluation

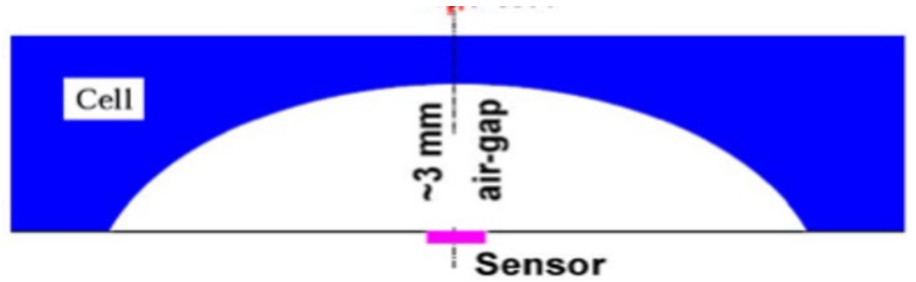
Scintillator tile testing

- Cosmics and Sr source
  - Vary tile size (2x2, 5x5, 10x10)
  - Vary tile thickness (4, 6, 8, 12mm)
  - Vary SiPM placement (center, corner, edge)
- Performance evaluation
  - Light yield per MIP, uniformity, cross-talk

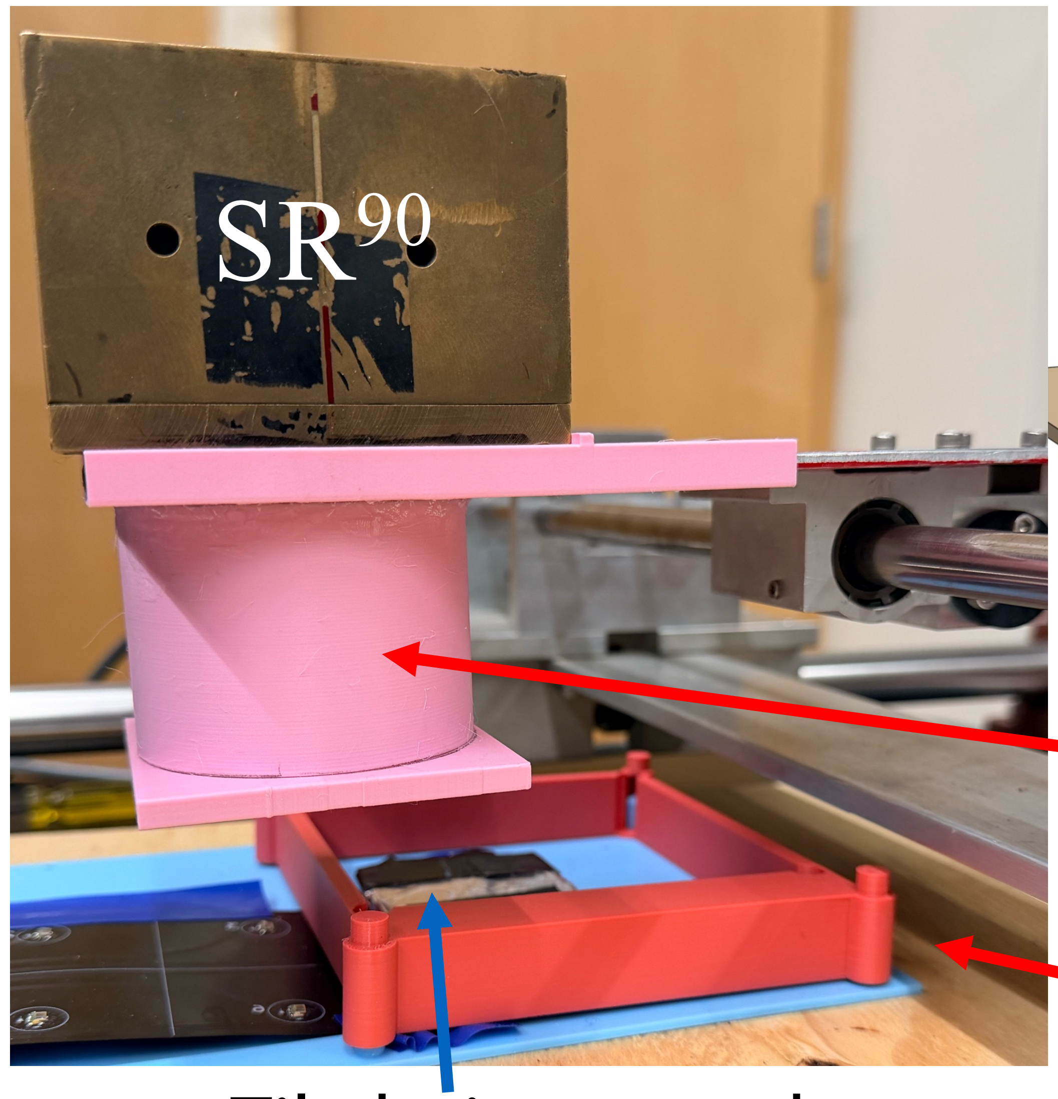
GOAL: verify 10x10 cm tile configuration

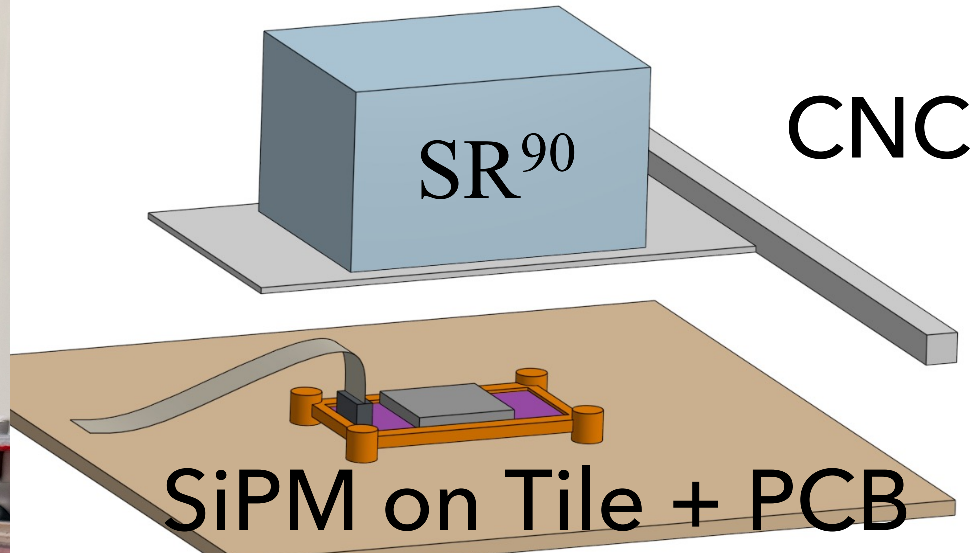
signal from SiPM-on-tile





Fully automated (CNC driven) tile-testing apparatus



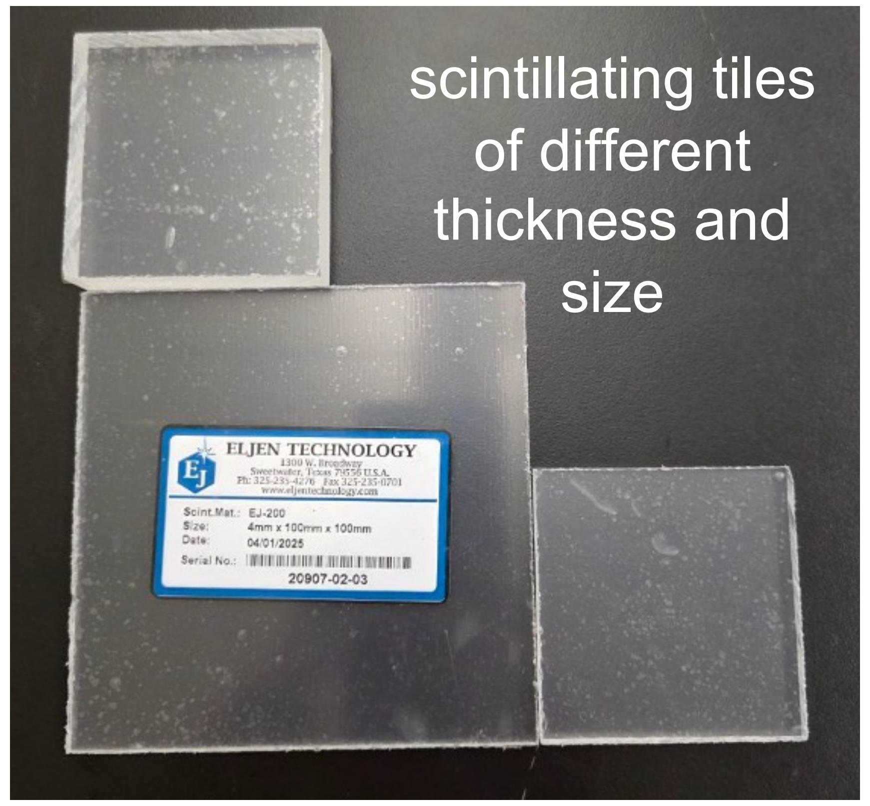


CNC system

Pb collimator provides ~5mm beam profile FWHM

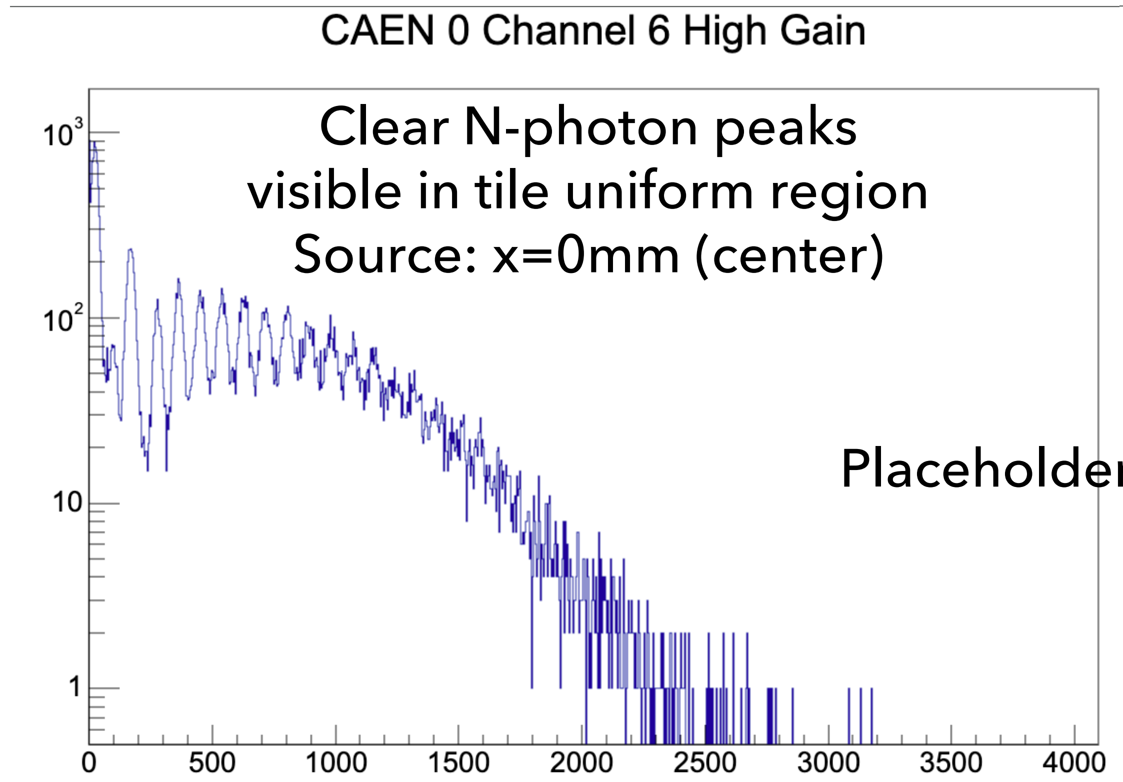
3D printed custom flexible PCB holder & light shield

Tile being tested

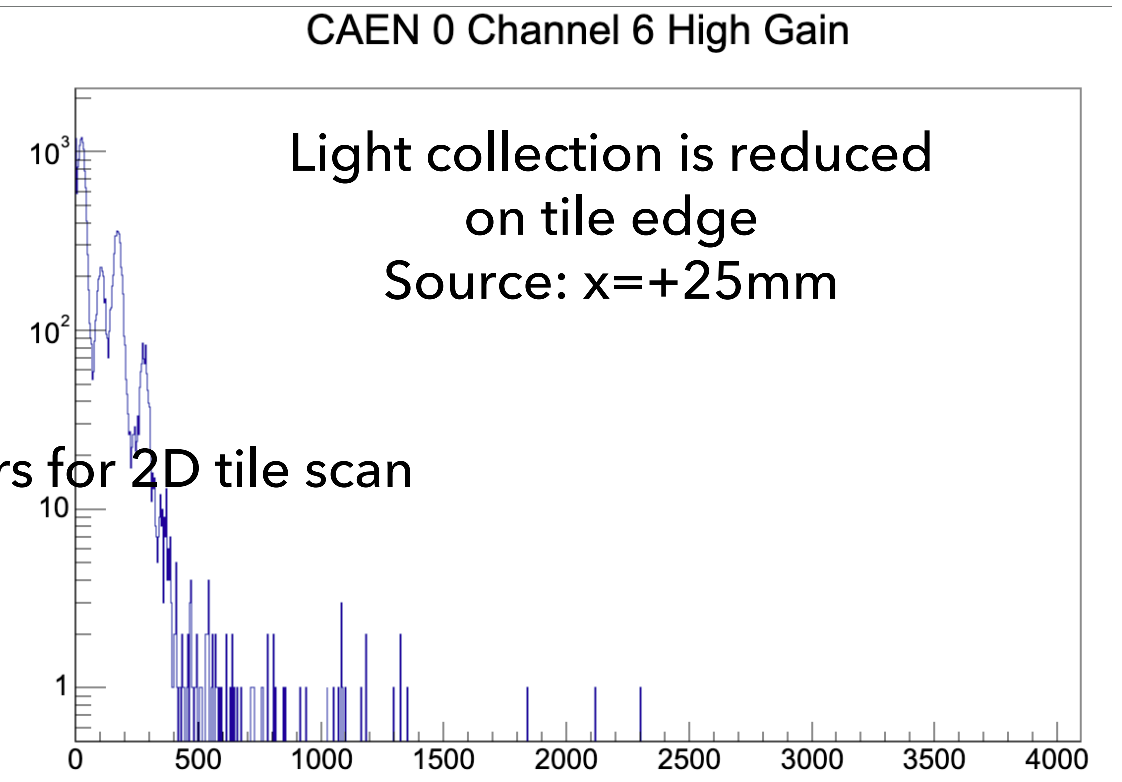


M. Stefaniak, Y. Khyzhniak, A. Molodtsova, O. Manger, A. Edgell (OSU)

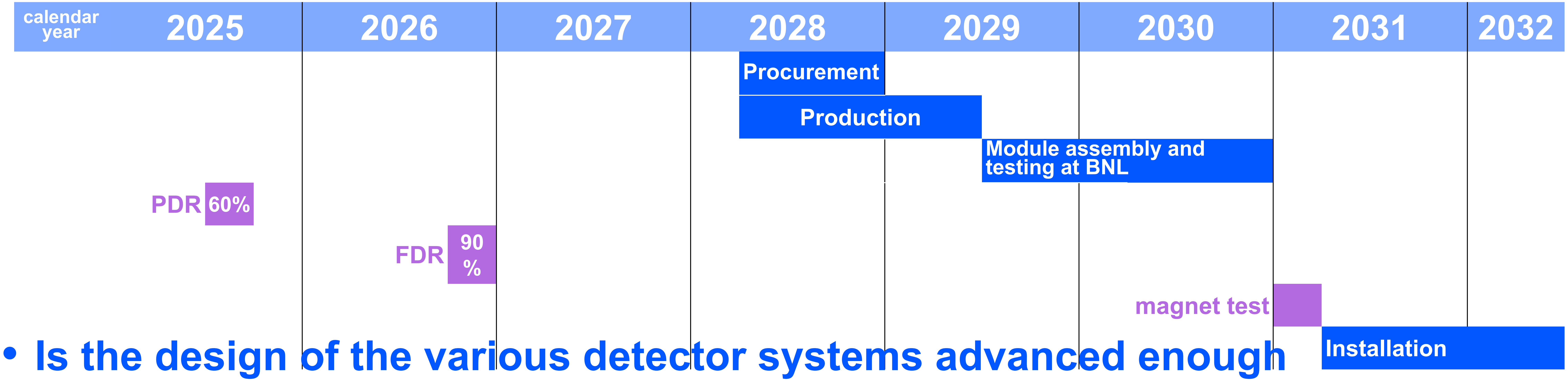
CAEN module for SiPM bias and DAQ



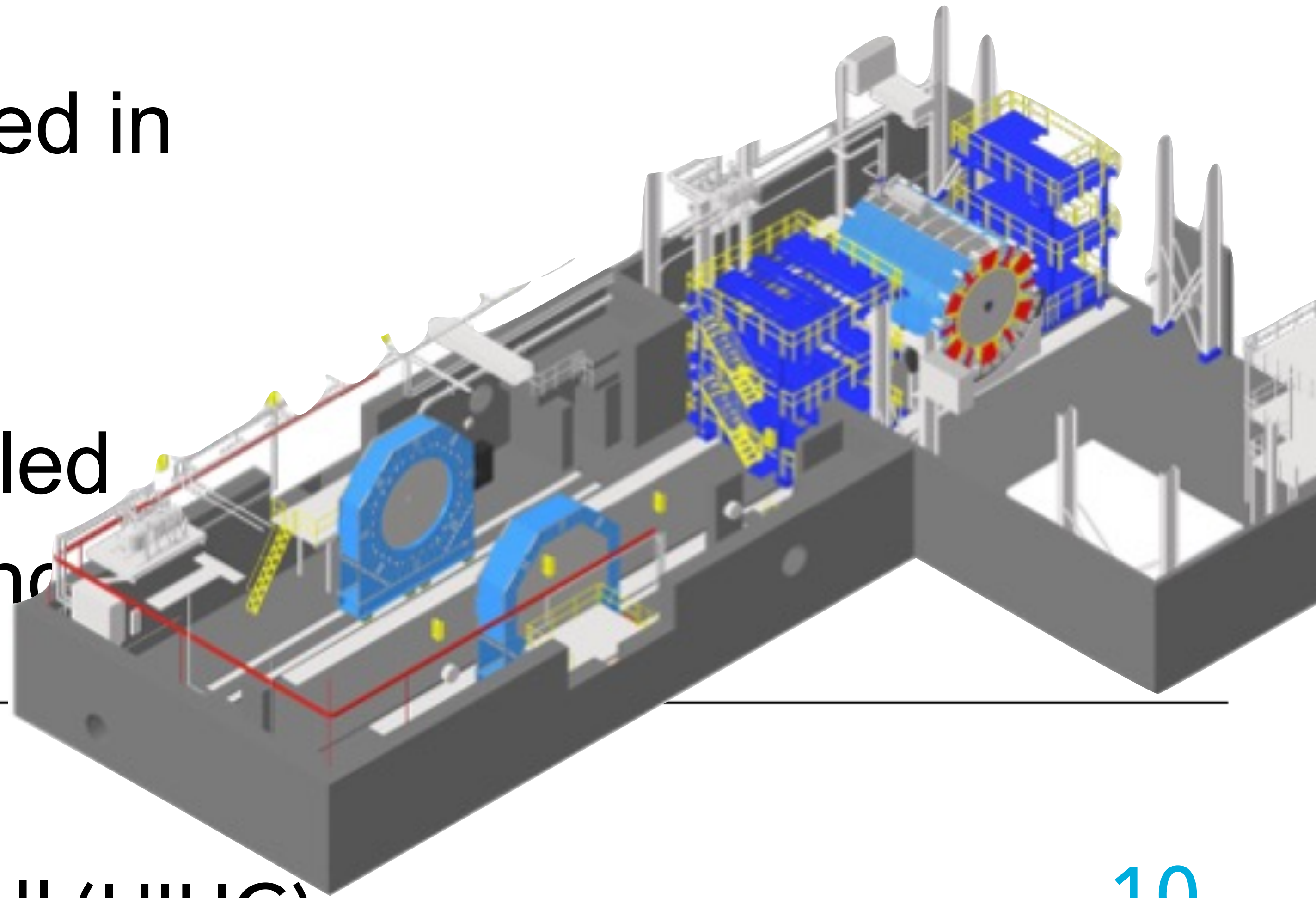
Placeholders for 2D tile scan



nHCal baselining and start of construction

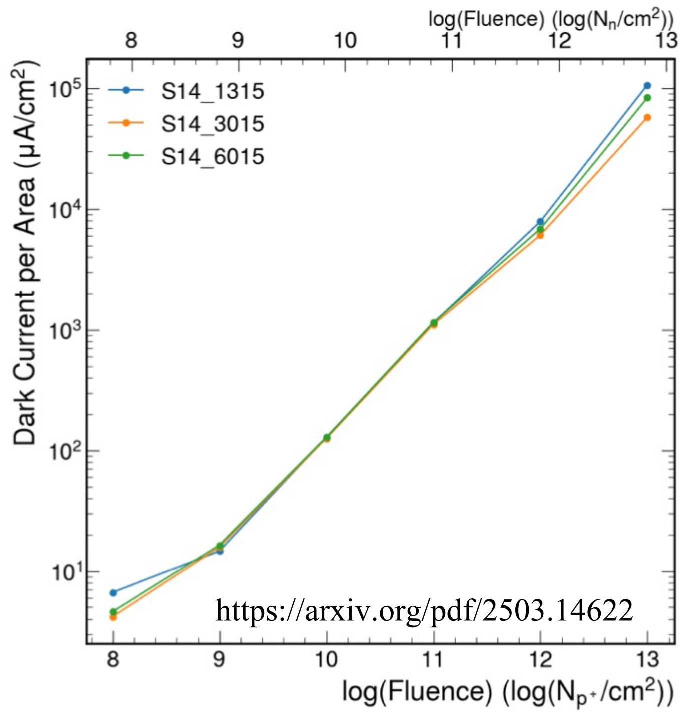


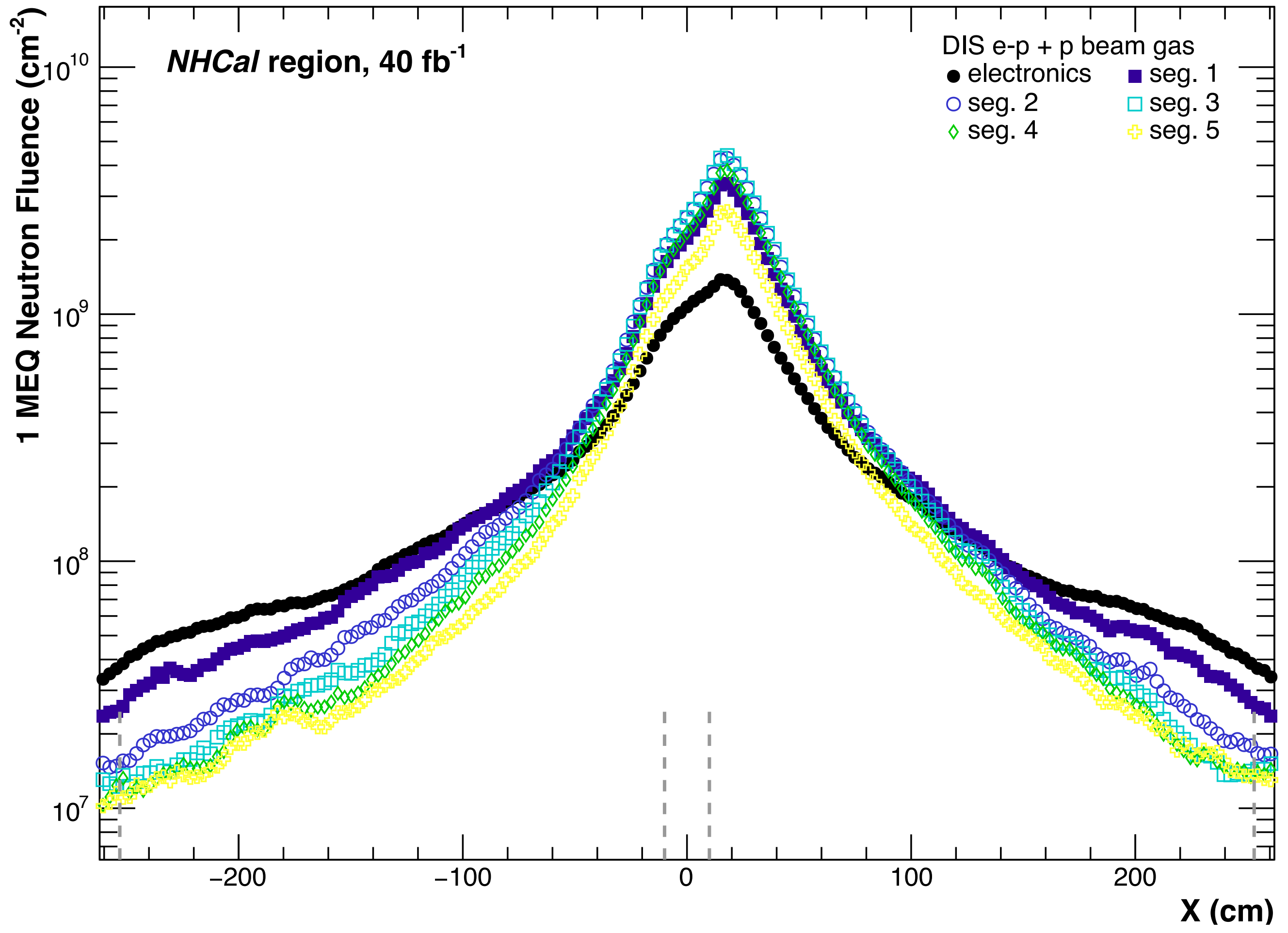
- **Is the design of the various detector systems advanced enough and appropriately documented for this stage of the project?**
  - Majority of design parameters have been optimized by simulation-based studies (TBD: readout layer integration)
  - Optimization parameters based on single particle simulations need to be confirmed in full simulation with background
  - Detector studies, optimization, and physics impact documented in preTDR
  - The nHCal can be delivered later than most other detectors because it is decoupled from the flux return and does not need to be in place for the solenoid field mapping



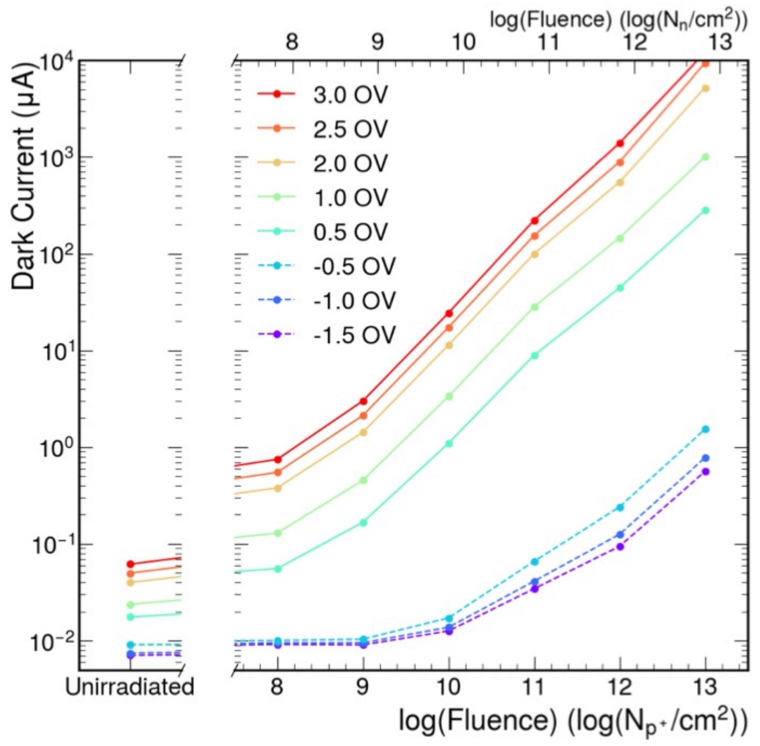
nHCal baselining and start of construction

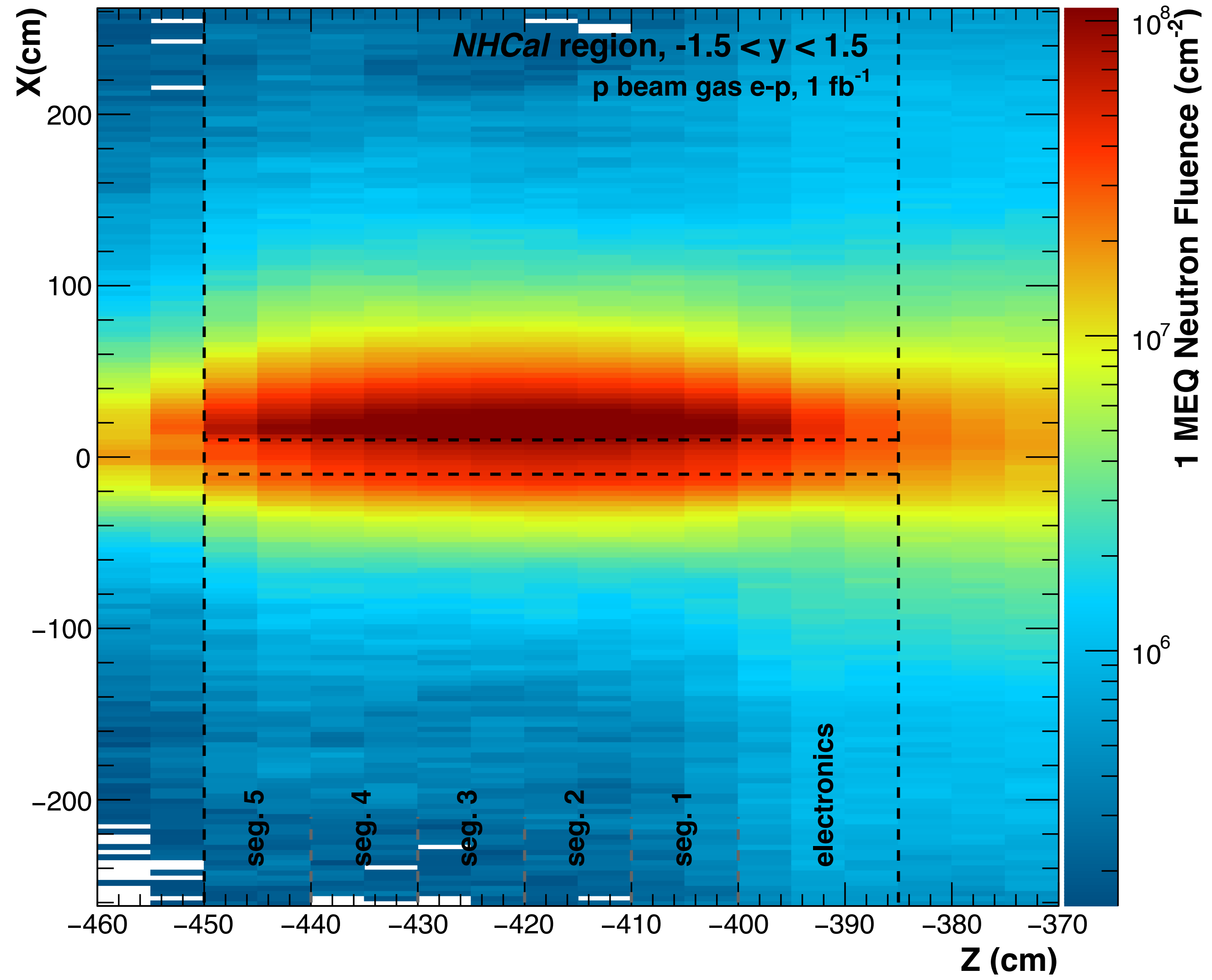
- **Are the current detector plans likely to achieve the performance requirements for the lifetime of the EIC physics program?**
  - HCALs are traditionally very robust detectors
  - Degradation of SiPM due to radiation damage has been studied (https://arxiv.org/pdf/2503.14622)
  - Expected SiPM lifetime sufficient for > 15 years of anticipated dosage





- **Have ES&H and quality assurance considerations been adequately incorporated into the plans at the present stage?**
  - We are (and will) follow and adhere to all applicable ES&H standards during the development, prototype, construction and testing.
  - Calorimeter absorber chosen for safety, magnetic constraints, physics motivations.
  - Use of radioactive sources for testing follow all local & institutional guidelines
  - Quality Assurance protocols are in place for the testing of modules, light-tight testing of tiles, consistency of SiPMs and module assembly





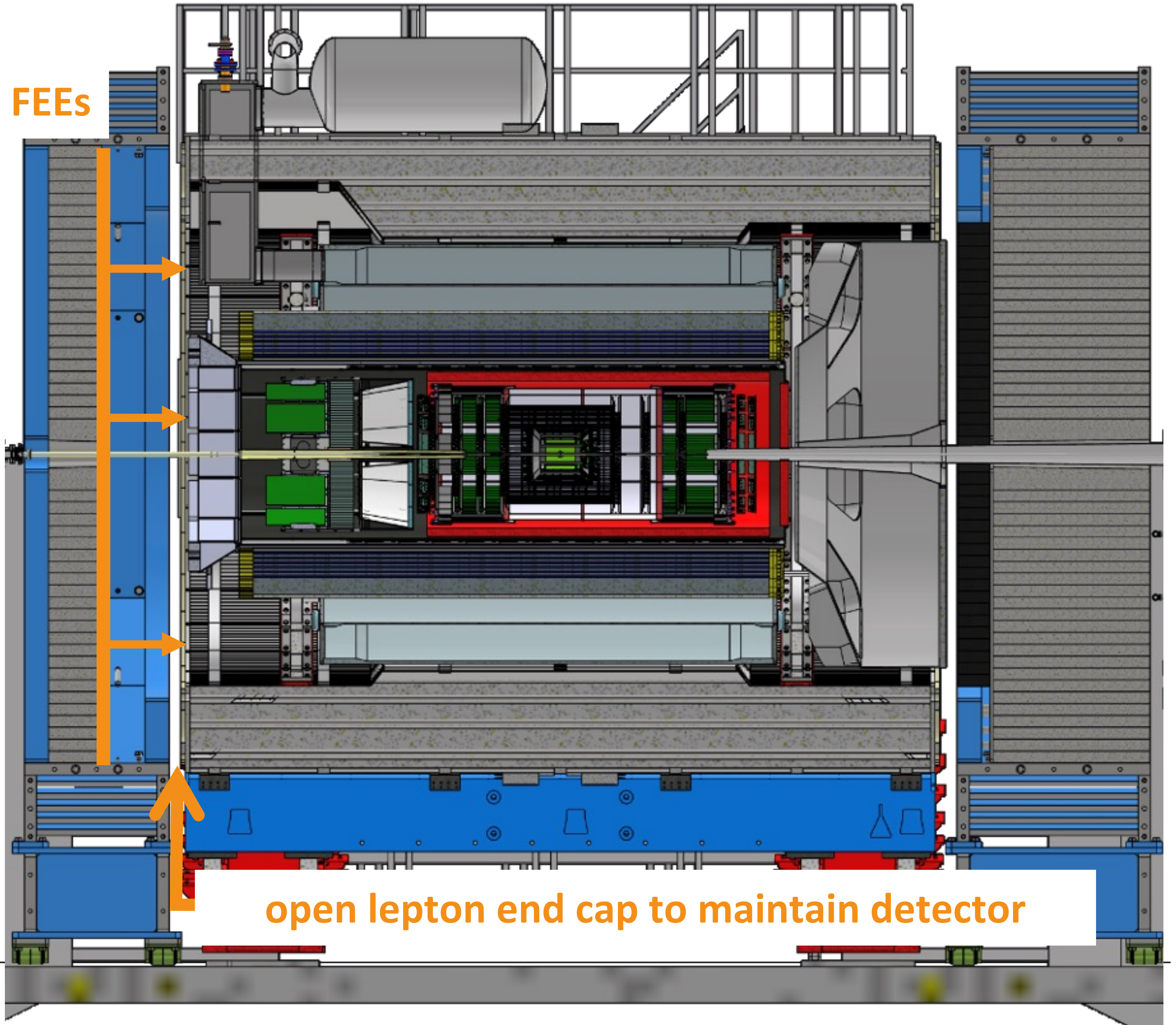
nHCal integration and planning for installation & maintenance

- **Are the assumptions for construction and fabrication of the various detector components sound and are assembly plans reasonable and consistent with the overall detector schedule?**

- Integration: services (LV, signal, slow control cables) and possibly cooling
  - Total dissipated heat: 0.5-2.4 kW (10cmx10cm tiles)
  - FEEs towards the IP ⇒ nHCal has to be serviced and maintained from the front (unlike LFHCal)

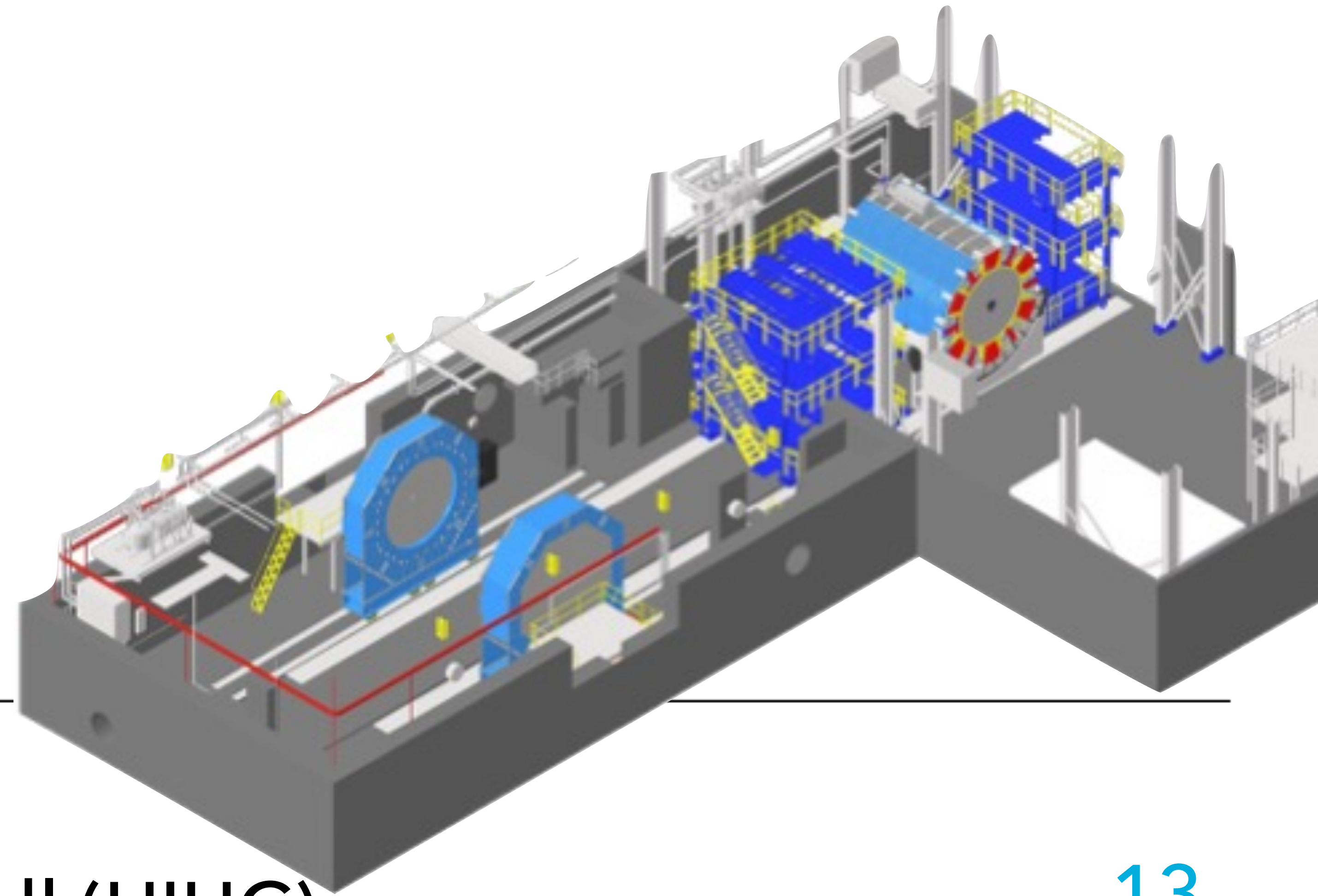
Services Summary

Item	Cross Sectional Area	Units	Endpoint 1	Endpoint 2
LV cable to FEE	24x1.13	cm2	FEE	Rack
Data signal cable	24x3.3912	cm2	FEE	Rack
Slow controls cable	24x0.07065	cm2	FEE	Rack



nHCal baselining and start of construction

- **Have recommendations from previous reviews been adequately addressed?**
- **Utilize technologic synergy with LFHCAL**
- **Incorporation of muon identification and acceptance into HCAL system design**
- **Study Impact on vector meson acceptance**
- **Detector optimization based on tail-catcher role and lessons learned from H1 SPACAL**
- **Consider the pros/cons of SiPM on tile vs wavelength shifting fiber / bars for light collection**



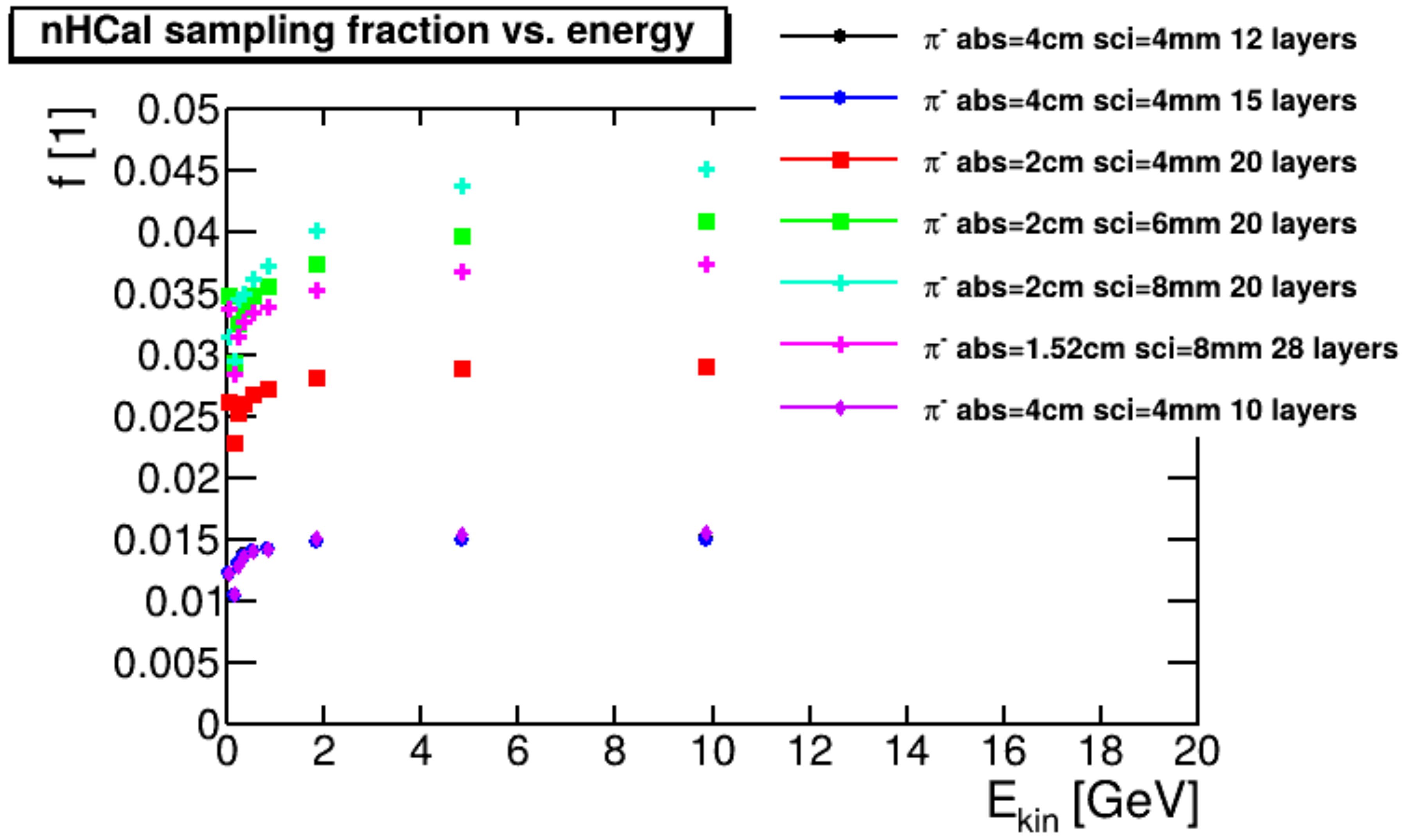
nHCal summary

- Status:
  - Synergy with LFHCAL technology, with design of nHCAL optimized for ‘tail-catcher’ role in ePIC
  - Actively testing scintillating tiles at OSU to verify 10x10cm SiPM on tile viability
    - Simulation studies on physical performance impact from non-linearity in light collection across tile transverse distance
  - ~80% of design parameters have been optimized in simulation
    - TODO: Layer readout integration to potentially reduce channel count, optimize first layer scintillator thickness
    - Incorporate backgrounds into ‘full’ event simulations
- What is missing until CD-2:
  - Completion of lab tests on SiPM and simulation campaigns including full simulations (end of year)
  - Desire of beam tests with neutron and muon beams to verify simulations and characterize performance
- Involved institutions: OSU, UIUC, CTU, BNL

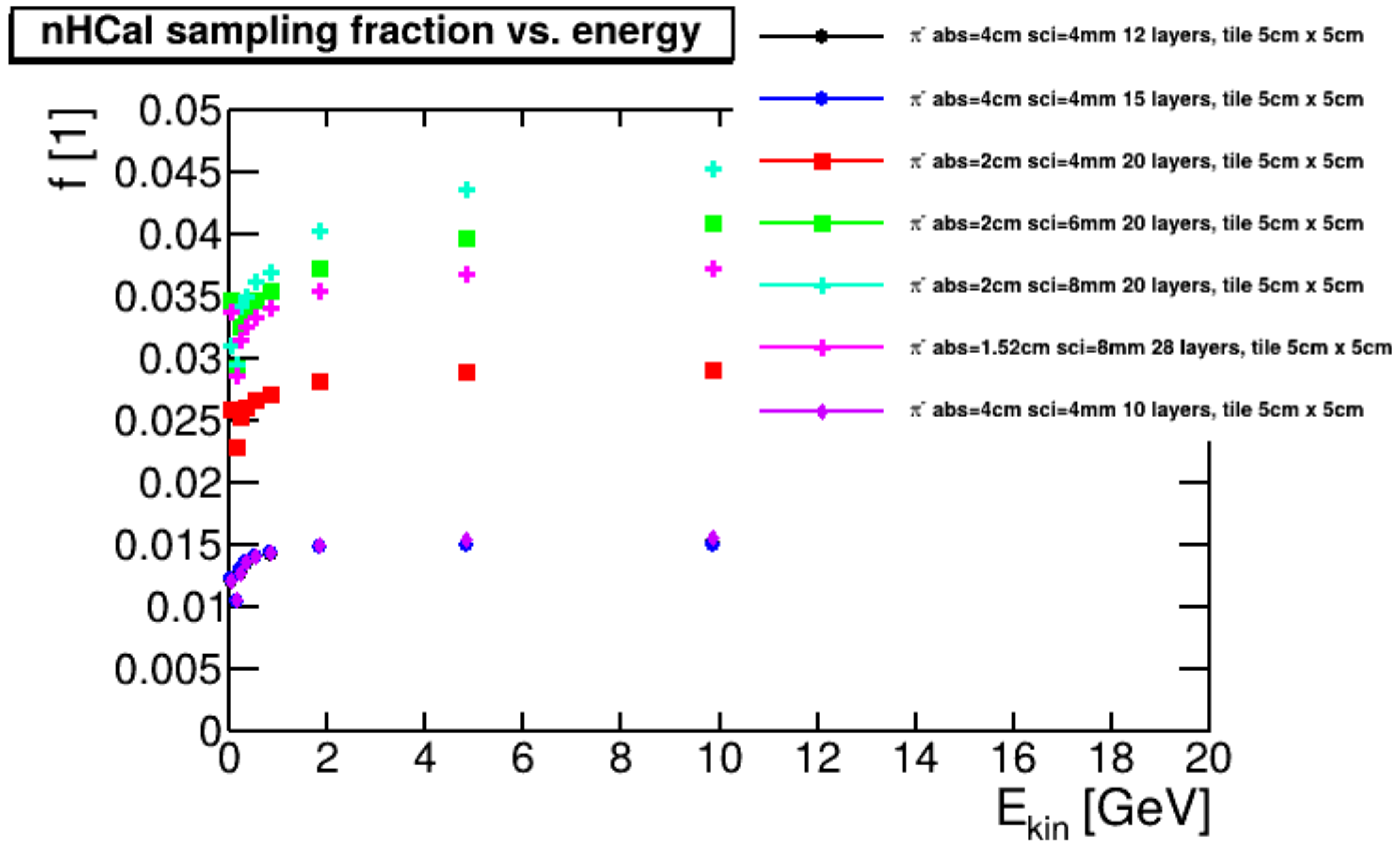
backup slides

Sampling fractions

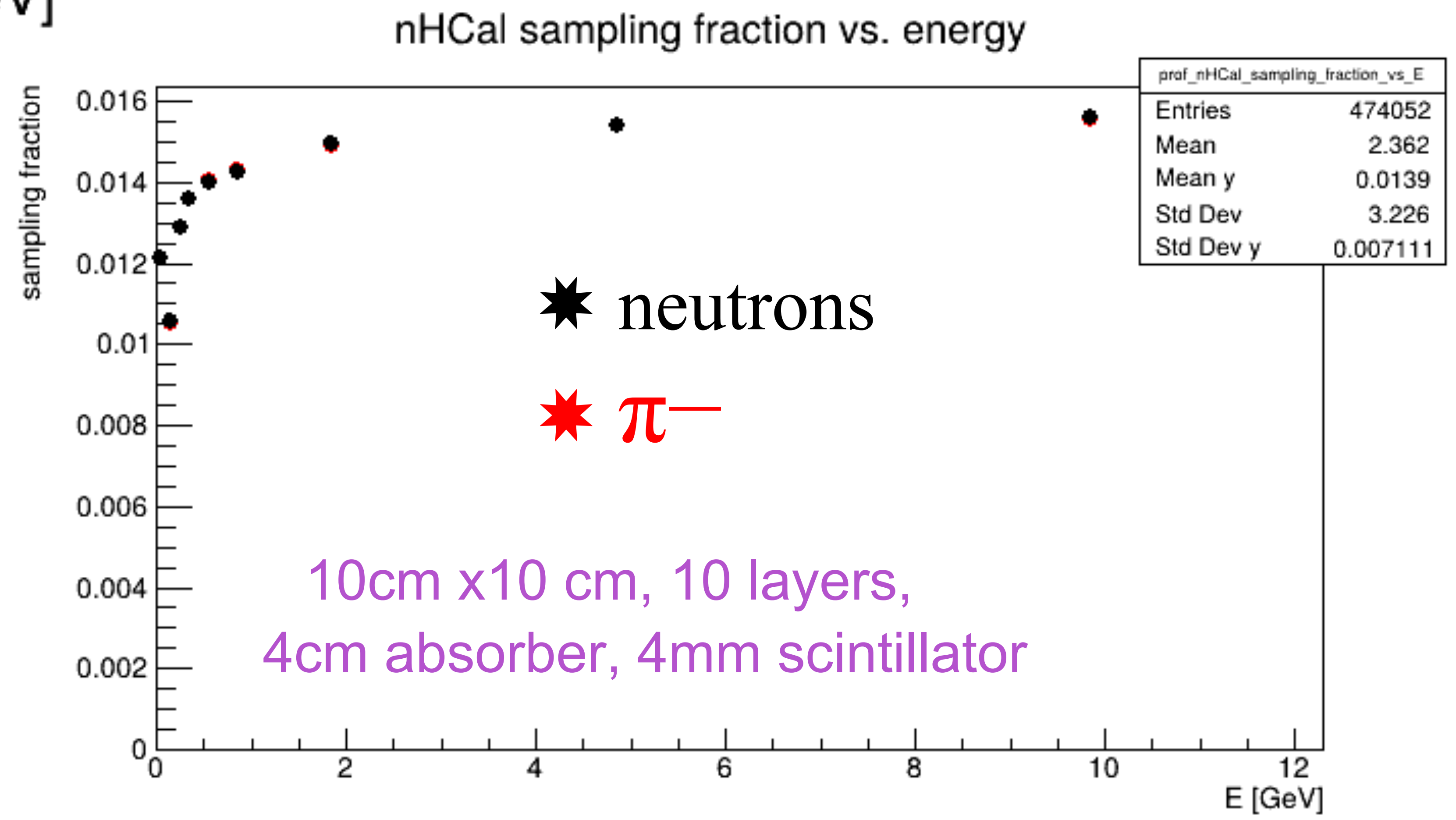
10cm x 10cm tiles



5cm x 5cm tiles



- Top row: vary geometry
- Right: vary particle species



nHCal project design - purposes and requirements

Purpose		Requirements
Low x and Q^2, high y high gluon densities		Coverage in backwards direction
diffraction	vector mesons	Good μ/π separation via MIP signal
	dijets	High efficiency for low-energy neutron detection
Neutral jets / neutral veto		
Charged jets		Good spatial resolution to distinguish clusters (neutral vs. charged)
Scattered **electron ID** (h veto)		
Improved hermiticity (↗ kinematic resolution in CC)		Good timing resolution

nHCal crucial for core aspects of EIC physics mission

Lessons from HERA / H1 backward SPACAL

NIMA 386 (1997), 397-408
PLB 665 (2008), 139-146

nHCal default design - parameters

nHCal similar but not identical to **LFHCal** design. Both are based on the sampling calorimeter technology with alternating layers of absorber and scintillator

	nHCal	LFHCal
material	same	Fe / SciTiles
interaction length	2.4	6.0
depth along beam axis	45cm	132cm
number of physical layers	10	60
thickness of layers	40mm / 4mm	16mm / 4mm
tile size	10cm x 10cm	5cm x 5cm
module size	10cm x 20cm x 45cm (8M), 10cm x 10cm x 45cm (4M)	10cm x 20cm x 140cm (8M), 10cm x 10cm x 140cm (4M)
number of modules	same	1058 (8M), 72 (4M)
tiles per layer	2x (1058+72)	8x (1058+72)
number of ROC	10x 2x (1058+72)=22,600	6x 8x (1058+72)=54,240

(+ insert modules)